Erik Dahlquist
Stefan Hellstrand *Editors*

Natural Resources Available Today and in the Future

How to Perform Change Management for Achieving a Sustainable World

Springer

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ISBN 978-3-319-54261-4 ISBN 978-3-319-54263-8 (eBook)
DOI 10.1007/978-3-319-54263-8

Library of Congress Control Number: 2017944432

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Natural resources have always been a limiting factor for human development. Once upon a time, it was large animals to hunt, which led to the extinction of large animals tens of thousands of years ago. When farming became more common, the population grew fast until, 1500–500 years ago. New farming methods using fertilizers more systematically developed, and during the 1960s–1970s, there was a new farm revolution, when new species combined with increased use of synthetic fertilizers, fossil fuels, and irrigation gave a doubling of production within a few decades. Along with these resource extensions we also got a strong population growth.

During the 1960s and 1970s, a major concern was that there would not be enough food for the growing population and in parallel the threat that from a large-scale nuclear war could eliminate human life from earth. During the 1990s–2000s, dramatic changes in politics took away the fear for the global nuclear war as the Soviet Union Empire collapsed.

The increase in food production has even reduced the absolute number of poor people by 50% at the same time as population doubled from the 1960s. Especially in East and South Asia, the development of society has been very impressive.

Now we are in a situation where many people aspire to have their own mobile phone, TV, computer, refrigerator, car, etc. This demands huge amounts of materials. Fertilizers demand phosphorous and energy-intensive nitrogen compounds. At the same time, we can see that easy-to-extract oil is starting to run out. It becomes more and more expensive to take up from wells from more remote areas and harsher climates like north of Norway and Canada. All these intricacies put a strong pressure for finding new solutions to sustain a wealthy society, and give those who are still poor good living conditions.

The goal of this book is to identify the available resources and to discuss how these resources can be utilized in a feasible way. We have huge amounts of biomass that could be used more efficiently. Phosphorous is a limiting element, but it could be recycled more efficiently. Different metals could be recycled, but they can be also replaced with more common if technology is developed further, like using FeS, CuO, and similar instead of rare elements in solar cells (PV). Breeding of cattle could be done in different ways to reduce emission of CO2, and other crops can be used as food to decrease the environmental burden. Insects can be used as protein source, as well as soya for direct use for humans.

We hope this book will both give hard facts and inspire the reader to look for new possibilities for future development.

Vasteras, Sweden — Erik Dahlquist
Kil, Sweden — Stefan Hellstrand

About the Author

Dr. Erik Dahlquist is Professor of Energy Technology and Research Director of the School of Business, Society & Engineering at Mälardalen University in Sweden since 2000. Dr. Dahlquist worked for 27 years in the energy-power industry, holding a number of research and management positions with ABB from 1975 to 2002. He was Deputy Dean and later Dean of the Faculty of Natural Science and Technology at Mälardalen from 2001 to 2007. He is now Research Director for the research profile Future Energy Center. Dr. Dahlquist's current research foci include Process Development for Renewable and Sustainable Energy Products, Energy and Efficient Power Load Management for Grids, Industry and Buildings, and Environmental Management. He is a member of the Swedish Royal Academy of Engineering Sciences and coordinator for the EU Horizon 2020 project FUDIPO, Future Direction of Process Industry Optimization in the SPIRE-2 program.

Dr. Stefan Hellstrand
Hellstrand holds a PhD in Energy and Environmental Engineering, PhLic in Systems Ecology – Natural Resource Management, and MSc in Agriculture – Animal Husbandry. He has during more than three decades combined academic work with advanced consultancy. Reality itself has been utilized as a laboratory of reality, to which specific questions are asked, where the answers express the relevance and robustness of the academic work. Simultaneously, customers are introduced to knowledge at the scientific frontier or ahead of it, where they decide by themselves whether it is for the benefit of their organization to take the chance and risk to utilize it. This represents a process for methodological development where the commercial market is used as a prober in the academic work, at the same time as short- and long-term objectives of customers are fulfilled. Through this process a toolkit supporting a sustainable development has emerged, that when applied in reality has contributed to sustainable intensification, supporting 14 of 16 environmental quality objectives in Sweden, several of the eight Millennium Development Goals, and with the capacity to support the 17 UN Sustainable Development Goals. Through these tools, causal chains can be followed in systems characterized by mutual dependencies between systems and systems levels, thresholds, and irreversibilities, that is, the

complexity of life as defining systems characteristics. This integrates agricultural sciences, system ecology, economic theory, applied environmental sciences, life-cycle assessment, and integrative assessment.

Description

This book focuses on providing an overview of all our available natural resources, considering the sustainability and potential for power generation of each. Energy efficiency prospects of each natural resource are examined in the context of society's key energy needs—heating/cooling, electric power, transportation, and industrial production. Geography, climate, and demographics are all discussed as key vectors impacting the comparative opportunities for self-sustenance around the globe. The authors provide in-depth coverage of renewable energy upscale and energy efficiency improvements in industry and society within a historical context, including a keen look at the variable effectiveness of different policy tools that have been used to support the transition away from unsustainable resource use. Finally, suggestions for more sustainable futures are provided, from improved policy measures, to new technological horizons in areas from offshore wind and marine energy to biogas and energy storage.

Other Authors

Professor Bert Allard, Örebro University, Sweden. Bert Allard has a long academic career working in the energy and environmental science area. He received his PhD in Environmental Chemistry from Chalmers University in 1975 and was Professor at first Linkoping University and also at Orebro University. Since 1997, he is a member of the royal academy of science (KVA), where he is Chairman for the Geoscience Department, which also is one of the departments proposing who should be awarded the Nobel Prize in Chemistry annually. He has contributed to this book by giving input to especially the chapters on inorganic resources.

Professor Elias Hakalehto, PhD, serves as an Adjunct Professor in Microbiological Agroecology at the University of Helsinki, Helsinki, Finland, and as an Adjunct Professor in Biotechnical Microbe Analytics at the University of Eastern Finland, Kuopio. He has participated with his R&D company, Finnoflag Oy, in more than 100 specific investigation tasks in industrial hygiene monitoring, environmental protection, diagnostics, bioprocess development, clinical microbiology, and probiotics. He is the author or editor of several scientific books in the fields of microbiology and biotechnology. He has contributed to scientific articles and patents in molecular microbiology, metabolic studies of microorganisms, as well as circulation, microbiomes, and biorefineries. Dr. Hakalehto has been the principal technology provider in the six-nation EU Baltic Sea Biorefinery project ABOWE in 2012–2014.

Mr. Ari Jääskeläinen, MSc (Industrial Management, with technological orientation in environmental protection technology) and BSc (Social Sciences), serves since 2005 as a Project Engineer and Lecturer in the Environmental Engineering, Teaching and Research unit of Savonia University of Applied Sciences, Kuopio, Finland. He has managed or been involved in several international and regional EU projects within environmental technology and business field.

Dr. Peter Stigson is Head of Sustainable Strategies and Resources at COWI, being an active Researcher and Consultant in resource efficiency and nexus approaches as well as international and national climate and energy policy and technology developments. More specifically, his interest lies in effective promotion of resource efficiency and systems governance through the application of nexus approaches, i.e., analyzing synergies and trade-offs between ecological and societal systems, such as energy, water, and land use that are often dealt with in isolation. Parallel to his position at COWI, Peter holds a position as Senior Lecturer at the School of Business, Society and Engineering, Mälardalen University. His role at the university includes integrating interdisciplinary sustainability research into the graduate and postgraduate energy and environmental engineering studies.

Dr. Lars Drake is a Consulting Professor (em) in Natural Resource and Environmental Economics at the Swedish University of Agricultural Sciences. Dr. Drake's research has been focused on resource and environmental problems of agriculture, including policy aspects, in Sweden, the EU, and East Africa. He has worked at the Swedish Environmental Protection Agency for 6 years and at the Swedish Chemicals Agency for 8 years.

Mrs. Malou Berndtsson holds a Masters (MSc) in Sustainable Development from Uppsala University and Swedish University of Agriculture as well as a Masters in International Economics and Business (MBA) from Linköping University. Her research has focused on Circular Economy, Sustainable Development, CSR Implementation, and Microfinance. She has been working as a management consultant in transformational processes as well as a nature guide.

Contents

Chapter 1
System Perspective

Erik Dahlquist and Stefan Hellstrand

1.1 Introduction

Today the total energy demand is ~140 000 TWh/y globally. Around 20 000 TWh/y of this is electricity. Approximately 80% of primary energy is from fossil fuel while ~20 000 TWh/y comes from renewable energy sources and approximately the same range from nuclear fuel (Wolrdbank 2011).

Some of the other resources we use are iron, copper, plastic, concrete, fertilizers, tensides etc. as well as wood and other cellulose based materials. There is a significant difference between populations concerning food with respect to cereals, meat etc. For example, in India most people are more or less vegetarians, while in Greenland meat dominates. The number of calories is still similar for most people independent of culture, but does depend on how much physical exercise is performed. Most males consume ~2700 kcal/day, while females average ~2400 kcal/d. How and where can the food be produced? How much primary energy is needed if we increase meat consumption, which is the trend in urban areas today; or a transfer to more vegetarian food, which is attractive for many youngsters today? Approximately 20–25% of the total energy used today is consumed for transportation, where most primary energy comes from fossil fuel. What would the system look like with only renewables and modern full electric or hybrid technologies?

The annual growth of biomass globally is almost double all primary energy used by the human population (Dahlquist 2013a). Practical potential for commercial

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Springer International Publishing AG 2017
E. Dahlquist, S. Hellstrand (eds.), *Natural Resources Available Today and in the Future*, DOI 10.1007/978-3-319-54263-8_1

biomass use is described by Slade et al. (2011) and UN-Energy (2007). Aside from biomass, we also have an enormous amount of other renewables. Currently, approximately 10% of electric power is produced using hydro and wind power, and solar power production is rapidly increasing (REN21 2011).

Comparison of the resource demand needed based on the average high, middle or low income inhabitant is interesting. It would also be interesting to see what production level can be achieved from agricultural areas if new technologies and species are considered, and recycling of waste performed to almost 100%.

Another aspect of sustainability is that all people should have enough to eat and other necessary resources like heat during winter, water and a sheltered room to live in. In wealthy countries in north Western Europe and North America this is considered as having expectations that are too low. In Sweden everyone should be guaranteed at least ~700 €/month, and if your salary is lower you usually get subsidies from the government. In many other countries the government does not give any support, and you have to rely on what you can earn yourself or together with your family. In many families this means that one or more persons have to go to cities or other countries to earn money, and then often send back money for the rest of the family to live on. Of course this creates the problem that the distribution of wealth is very unequal, as well as that we have different attitudes towards the role of government. In countries like China some functions are very efficient like hospitals, where the cost to get service is very low, while subsidies to the unemployed principally do not exist. In the US there are good conditions for those with a job, but quite poor support if the job is lost, as often pension and health care insurance is connected to the job.

It should also be noticed that the labor profile for jobs is continuously changing. In Sweden a recent study (Stefan Fölster 2015) estimated 450 000 jobs were replaced by automation and robots between 2006 and 2011. This is almost 10% of the total workforce of ~5 500 000 people. Still at the same time, the number of employed people rose by 100 000 through new jobs, as well as replacements for those removed. The trend is to have more jobs in IT and automation (+ 50 000 people) as well as in sales of advanced products like electronics and other consumer goods. Although the development of computer games has been very successful in Sweden, there are only ~10 000 people employed in this branch. It is similar for big companies in the US like Google, Apple and Microsoft. These companies create great value in products, but do not employ many people.

This presents a problem since by tradition we have assumed that industry should drive the development. Now, we see a down trend of less qualified jobs in industry. The increase of qualified engineering jobs is by far not replacing the number of less qualified jobs from a numbers perspective. If 100 less qualified jobs are gone, only 20 new engineering jobs are created. In developed countries we have already seen this trend in agriculture, where some 2–3% of the population produces the food we need. What sectors shall all the new jobs be in? How can the government get enough tax to handle all functions needed by the population?

If we look at the global situation over the last 50 years we can see many positive signs (UNFPA 2011). Extreme poverty, defined as an income below 1.9 USD per day per capita, has been halved from 1990 to 2015. Today 700 million people

(= 10%) have this income while it was 40% in 1990! The situation has much improved in China and India, while many in Africa South of the Sahara are still very poor. Life expectancy has also improved from 52 years in 1960 to more than 70 years today! We have also become generally healthier due to better food quality and quantity, new medicines, better water quality and hygiene. There is still potential for significant improvements, such as good toilets, while antibiotic resistant microorganisms are a new threat. Today, bacteria resistant to all known antibiotics exist in all parts of the world, although more so in countries using antibiotics too frequently. A more restrictive use is promoted and hopefully can reduce the risks. One significant problem is that pharmaceutical companies see development of this type of product as less profitable since society wants to push introducing new medicines at a cheap price, which makes it difficult to earn money. Government funded development by universities and institutes may be a way around this.

As a consequence of improved economy we also see that birth rate goes down. In almost all countries in the world except for Africa South of the Sahara we are down to levels below 1%/year. With improved economy, we probably will also see a decrease here, although those making predictions for the future still believe the population will substantially increase. A UN organization actually predicts an increase from around 1 to 4 billion by 2100. However, this assumes that the birth rate will stay at today's levels around 2.5%/year, and hopefully we will not see this since the economy has improved a lot over the last 10 years.

The number of children starting school has increased from 82% in 2005 to 90% in 2015, where the percentage in Africa South of the Sahara increased from 60 to 80% during this period. This is very promising and usually is followed by decreased birth rates and increased economy. New businesses in many countries in eastern, central and western Africa have great promise that hopefully is not counteracted by new wars. In many countries every person has a mobile phone, and new apps have replaced the need for banks. An agreement between supplier and buyer through these apps is made to pay and get paid. This reduces the demand for banks and probably will spread from Africa to the rest of the world! New mobile phone PV cell loading stations have spread and given new opportunities to many people!

By these new trends we hopefully can reduce poverty and get a more equal distribution of wealth, which also is a necessity for a sustainable society. Some important indices are followed by Wolrd Bank Development Indicators, such as

- Life expectancy index
- Human development index
- Education level index
- Gross national product (GNP) adjusted for purchasing power

The trends for these will be covered in more detail in the rest of this book.

Table 1.1 Grouping of countries into groups from an economical perspective

Heavily indebted poor countries (HIPC)	HPC
High income	HIC
High income: nonOECD	NOC
High income: OECD	OEC
Low & middle income	LMY
Low income	LIC
Lower middle income	LMC
Middle income	MIC
Upper middle income	UMC
World	WLD

1.2 Countries of the World: Countries Grouped in Different Categories

The United Nations (UN) collects a lot of data from all UN countries. For the time being 213 countries are listed. The countries are then grouped with respect to national income per capita (see Table 1.1).

This division has impacts on single countries from perspectives like who should get financial support from the others. For example, Sweden only gives economic support to countries belonging to the lower-mid-income group or lower. Other countries have similar rules. In Table 1.2 we see what countries are registered by the UN and what income group each country belongs to.

Some selected countries or regions with large populations are shown separately in Table 1.3.

Of these the EU and the US are considered high income countries/regions, while China, India and Brazil are in the med-income group. Russia is somewhere in-between. Together the population of these countries and regions is roughly 4 billion of the 7 billion world population.

In this book we also use geographic distribution. The different regions are seen in Table 1.4.

1.3 Sustainable Development of Cities and Societies

When talking about resources and sustainability we have to discuss development of energy efficient cities, sometimes called smart cities. Recently, in 2011, official figures stated that more people live in urban than rural areas.

The definition of sustainable cities and energy efficient cities is not very clear, but has been discussed in a number of projects and reports.

In the EU FP7 project PLEEC, Planning of Energy efficient cities, 18 partners in 13 countries in the EU participated and jointly developed a set of tools on how

Table 1.2 Data on separate countries recognized by the UN and what income group the country belongs to

Country code	Short name	Region	Income group
AFG	Afghanistan	South Asia	Low income
ALB	Albania	Europe & Central Asia	Upper middle income
DZA	Algeria	Middle East & North Africa	Upper middle income
ASM	American Samoa	East Asia & Pacific	Upper middle income
ADO	Andorra	Europe & Central Asia	High income: nonOECD
AGO	Angola	Sub-Saharan Africa	Upper middle income
ATG	Antigua and Barbuda	Latin America & Caribbean	High income: nonOECD
ARG	Argentina	Latin America & Caribbean	Upper middle income
ARM	Armenia	Europe & Central Asia	Lower middle income
ABW	Aruba	Latin America & Caribbean	High income: nonOECD
AUS	Australia	East Asia & Pacific	High income: OECD
AUT	Austria	Europe & Central Asia	High income: OECD
AZE	Azerbaijan	Europe & Central Asia	Upper middle income
BHR	Bahrain	Middle East & North Africa	High income: nonOECD
BGD	Bangladesh	South Asia	Low income
BRB	Barbados	Latin America & Caribbean	High income: nonOECD
BLR	Belarus	Europe & Central Asia	Upper middle income
BEL	Belgium	Europe & Central Asia	High income: OECD
BLZ	Belize	Latin America & Caribbean	Upper middle income
BEN	Benin	Sub-Saharan Africa	Low income
BMU	Bermuda	North America	High income: nonOECD
BTN	Bhutan	South Asia	Lower middle income
BOL	Bolivia	Latin America & Caribbean	Lower middle income
BIH	Bosnia and Herzegovina	Europe & Central Asia	Upper middle income
BWA	Botswana	Sub-Saharan Africa	Upper middle income
BRA	Brazil	Latin America & Caribbean	Upper middle income
BRN	Brunei	East Asia & Pacific	High income: nonOECD
BGR	Bulgaria	Europe & Central Asia	Upper middle income
BFA	Burkina Faso	Sub-Saharan Africa	Low income
BDI	Burundi	Sub-Saharan Africa	Low income

(continued)

Table 1.2 (continued)

Country code	Short name	Region	Income group
CPV	Cabo Verde	Sub-Saharan Africa	Lower middle income
KHM	Cambodia	East Asia & Pacific	Low income
CMR	Cameroon	Sub-Saharan Africa	Lower middle income
CAN	Canada	North America	High income: OECD
CSS	Caribbean small states		
CYM	Cayman Islands	Latin America & Caribbean	High income: nonOECD
CAF	Central African Republic	Sub-Saharan Africa	Low income
CEB	Central Europe and the Baltics		
TCD	Chad	Sub-Saharan Africa	Low income
CHI	Channel Islands	Europe & Central Asia	High income: nonOECD
CHL	Chile	Latin America & Caribbean	High income: OECD
CHN	China	East Asia & Pacific	Upper middle income
COL	Colombia	Latin America & Caribbean	Upper middle income
COM	Comoros	Sub-Saharan Africa	Low income
COG	Congo	Sub-Saharan Africa	Lower middle income
CRI	Costa Rica	Latin America & Caribbean	Upper middle income
CIV	Côte d’Ivoire	Sub-Saharan Africa	Lower middle income
HRV	Croatia	Europe & Central Asia	High income: nonOECD
CUB	Cuba	Latin America & Caribbean	Upper middle income
CUW	Curaçao	Latin America & Caribbean	High income: nonOECD
CYP	Cyprus	Europe & Central Asia	High income: nonOECD
CZE	Czech Republic	Europe & Central Asia	High income: OECD
PRK	Dem. People’s Rep. Korea	East Asia & Pacific	Low income
ZAR	Dem. Rep. Congo	Sub-Saharan Africa	Low income
DNK	Denmark	Europe & Central Asia	High income: OECD
DJI	Djibouti	Middle East & North Africa	Lower middle income
DMA	Dominica	Latin America & Caribbean	Upper middle income
DOM	Dominican Republic	Latin America & Caribbean	Upper middle income
ECU	Ecuador	Latin America & Caribbean	Upper middle income

(continued)

Table 1.2 (continued)

Country code	Short name	Region	Income group
EGY	Egypt	Middle East & North Africa	Lower middle income
SLV	El Salvador	Latin America & Caribbean	Lower middle income
GNQ	Equatorial Guinea	Sub-Saharan Africa	High income: nonOECD
ERI	Eritrea	Sub-Saharan Africa	Low income
EST	Estonia	Europe & Central Asia	High income: OECD
ETH	Ethiopia	Sub-Saharan Africa	Low income
FRO	Faeroe Islands	Europe & Central Asia	High income: nonOECD
FJI	Fiji	East Asia & Pacific	Upper middle income
FIN	Finland	Europe & Central Asia	High income: OECD
FCS	Fragile and conflict affected situations		
FRA	France	Europe & Central Asia	High income: OECD
PYF	French Polynesia	East Asia & Pacific	High income: nonOECD
GAB	Gabon	Sub-Saharan Africa	Upper middle income
GEO	Georgia	Europe & Central Asia	Lower middle income
DEU	Germany	Europe & Central Asia	High income: OECD
GHA	Ghana	Sub-Saharan Africa	Lower middle income
GRC	Greece	Europe & Central Asia	High income: OECD
GRL	Greenland	Europe & Central Asia	High income: nonOECD
GRD	Grenada	Latin America & Caribbean	Upper middle income
GUM	Guam	East Asia & Pacific	High income: nonOECD
GTM	Guatemala	Latin America & Caribbean	Lower middle income
GIN	Guinea	Sub-Saharan Africa	Low income
GNB	Guinea-Bissau	Sub-Saharan Africa	Low income
GUY	Guyana	Latin America & Caribbean	Lower middle income
HTI	Haiti	Latin America & Caribbean	Low income
HND	Honduras	Latin America & Caribbean	Lower middle income
HKG	Hong Kong SAR, China	East Asia & Pacific	High income: nonOECD
HUN	Hungary	Europe & Central Asia	Upper middle income
ISL	Iceland	Europe & Central Asia	High income: OECD
IND	India	South Asia	Lower middle income

(continued)

Table 1.2 (continued)

Country code	Short name	Region	Income group
IDN	Indonesia	East Asia & Pacific	Lower middle income
IRN	Iran	Middle East & North Africa	Upper middle income
IRQ	Iraq	Middle East & North Africa	Upper middle income
IRL	Ireland	Europe & Central Asia	High income: OECD
IMY	Isle of Man	Europe & Central Asia	High income: nonOECD
ISR	Israel	Middle East & North Africa	High income: OECD
ITA	Italy	Europe & Central Asia	High income: OECD
JAM	Jamaica	Latin America & Caribbean	Upper middle income
JPN	Japan	East Asia & Pacific	High income: OECD
JOR	Jordan	Middle East & North Africa	Upper middle income
KAZ	Kazakhstan	Europe & Central Asia	Upper middle income
KEN	Kenya	Sub-Saharan Africa	Low income
KIR	Kiribati	East Asia & Pacific	Lower middle income
KOR	Korea	East Asia & Pacific	High income: OECD
KSV	Kosovo	Europe & Central Asia	Lower middle income
KWT	Kuwait	Middle East & North Africa	High income: nonOECD
KGZ	Kyrgyz Republic	Europe & Central Asia	Lower middle income
LAO	Lao PDR	East Asia & Pacific	Lower middle income
LVA	Latvia	Europe & Central Asia	High income: nonOECD
LBN	Lebanon	Middle East & North Africa	Upper middle income
LSO	Lesotho	Sub-Saharan Africa	Lower middle income
LBR	Liberia	Sub-Saharan Africa	Low income
LBY	Libya	Middle East & North Africa	Upper middle income
LIE	Liechtenstein	Europe & Central Asia	High income: nonOECD
LTU	Lithuania	Europe & Central Asia	High income: nonOECD
LUX	Luxembourg	Europe & Central Asia	High income: OECD
MAC	Macao SAR, China	East Asia & Pacific	High income: nonOECD
MKD	Macedonia	Europe & Central Asia	Upper middle income
MDG	Madagascar	Sub-Saharan Africa	Low income
MWI	Malawi	Sub-Saharan Africa	Low income

(continued)

Table 1.2 (continued)

Country code	Short name	Region	Income group
MYS	Malaysia	East Asia & Pacific	Upper middle income
MDV	Maldives	South Asia	Upper middle income
MLI	Mali	Sub-Saharan Africa	Low income
MLT	Malta	Middle East & North Africa	High income: nonOECD
MHL	Marshall Islands	East Asia & Pacific	Upper middle income
MRT	Mauritania	Sub-Saharan Africa	Lower middle income
MUS	Mauritius	Sub-Saharan Africa	Upper middle income
MEX	Mexico	Latin America & Caribbean	Upper middle income
FSM	Micronesia	East Asia & Pacific	Lower middle income
MDA	Moldova	Europe & Central Asia	Lower middle income
MCO	Monaco	Europe & Central Asia	High income: nonOECD
MNG	Mongolia	East Asia & Pacific	Lower middle income
MNE	Montenegro	Europe & Central Asia	Upper middle income
MAR	Morocco	Middle East & North Africa	Lower middle income
MOZ	Mozambique	Sub-Saharan Africa	Low income
MMR	Myanmar	East Asia & Pacific	Low income
NAM	Namibia	Sub-Saharan Africa	Upper middle income
NPL	Nepal	South Asia	Low income
NLD	Netherlands	Europe & Central Asia	High income: OECD
NCL	New Caledonia	East Asia & Pacific	High income: nonOECD
NZL	New Zealand	East Asia & Pacific	High income: OECD
NIC	Nicaragua	Latin America & Caribbean	Lower middle income
NER	Niger	Sub-Saharan Africa	Low income
NGA	Nigeria	Sub-Saharan Africa	Lower middle income
MNP	Northern Mariana Islands	East Asia & Pacific	High income: nonOECD
NOR	Norway	Europe & Central Asia	High income: OECD
OMN	Oman	Middle East & North Africa	High income: nonOECD
OSS	Other small states		
PSS	Pacific island small states		
PAK	Pakistan	South Asia	Lower middle income
PLW	Palau	East Asia & Pacific	Upper middle income
PAN	Panama	Latin America & Caribbean	Upper middle income
PNG	Papua New Guinea	East Asia & Pacific	Lower middle income

(continued)

Table 1.2 (continued)

Country code	Short name	Region	Income group
PRY	Paraguay	Latin America & Caribbean	Lower middle income
PER	Peru	Latin America & Caribbean	Upper middle income
PHL	Philippines	East Asia & Pacific	Lower middle income
POL	Poland	Europe & Central Asia	High income: OECD
PRT	Portugal	Europe & Central Asia	High income: OECD
PRI	Puerto Rico	Latin America & Caribbean	High income: nonOECD
QAT	Qatar	Middle East & North Africa	High income: nonOECD
ROM	Romania	Europe & Central Asia	Upper middle income
RUS	Russia	Europe & Central Asia	High income: nonOECD
RWA	Rwanda	Sub-Saharan Africa	Low income
WSM	Samoa	East Asia & Pacific	Lower middle income
SMR	San Marino	Europe & Central Asia	High income: nonOECD
STP	São Tomé and Principe	Sub-Saharan Africa	Lower middle income
SAU	Saudi Arabia	Middle East & North Africa	High income: nonOECD
SEN	Senegal	Sub-Saharan Africa	Lower middle income
SRB	Serbia	Europe & Central Asia	Upper middle income
SYC	Seychelles	Sub-Saharan Africa	Upper middle income
SLE	Sierra Leone	Sub-Saharan Africa	Low income
SGP	Singapore	East Asia & Pacific	High income: nonOECD
SXM	Sint Maarten (Dutch part)	Latin America & Caribbean	High income: nonOECD
SVK	Slovak Republic	Europe & Central Asia	High income: OECD
SVN	Slovenia	Europe & Central Asia	High income: OECD
SLB	Solomon Islands	East Asia & Pacific	Lower middle income
SOM	Somalia	Sub-Saharan Africa	Low income
ZAF	South Africa	Sub-Saharan Africa	Upper middle income
SSD	South Sudan	Sub-Saharan Africa	Lower middle income
ESP	Spain	Europe & Central Asia	High income: OECD
LKA	Sri Lanka	South Asia	Lower middle income
KNA	St. Kitts and Nevis	Latin America & Caribbean	High income: nonOECD
LCA	St. Lucia	Latin America & Caribbean	Upper middle income
MAF	St. Martin (French part)	Latin America & Caribbean	High income: nonOECD

(continued)

Table 1.2 (continued)

Country code	Short name	Region	Income group
VCT	St. Vincent and the Grenadines	Latin America & Caribbean	Upper middle income
SDN	Sudan	Sub-Saharan Africa	Lower middle income
SUR	Suriname	Latin America & Caribbean	Upper middle income
SWZ	Swaziland	Sub-Saharan Africa	Lower middle income
SWE	Sweden	Europe & Central Asia	High income: OECD
CHE	Switzerland	Europe & Central Asia	High income: OECD
SYR	Syrian Arab Republic	Middle East & North Africa	Lower middle income
TJK	Tajikistan	Europe & Central Asia	Low income
TZA	Tanzania	Sub-Saharan Africa	Low income
THA	Thailand	East Asia & Pacific	Upper middle income
BHS	The Bahamas	Latin America & Caribbean	High income: nonOECD
GMB	The Gambia	Sub-Saharan Africa	Low income
TMP	Timor-Leste	East Asia & Pacific	Lower middle income
TGO	Togo	Sub-Saharan Africa	Low income
TON	Tonga	East Asia & Pacific	Upper middle income
TTO	Trinidad and Tobago	Latin America & Caribbean	High income: nonOECD
TUN	Tunisia	Middle East & North Africa	Upper middle income
TUR	Turkey	Europe & Central Asia	Upper middle income
TKM	Turkmenistan	Europe & Central Asia	Upper middle income
TCA	Turks and Caicos Islands	Latin America & Caribbean	High income: nonOECD
TUV	Tuvalu	East Asia & Pacific	Upper middle income
UGA	Uganda	Sub-Saharan Africa	Low income
UKR	Ukraine	Europe & Central Asia	Lower middle income
ARE	United Arab Emirates	Middle East & North Africa	High income: nonOECD
GBR	United Kingdom	Europe & Central Asia	High income: OECD
USA	United States	North America	High income: OECD
URY	Uruguay	Latin America & Caribbean	High income: nonOECD
UZB	Uzbekistan	Europe & Central Asia	Lower middle income
VUT	Vanuatu	East Asia & Pacific	Lower middle income
VEN	Venezuela	Latin America & Caribbean	Upper middle income
VNM	Vietnam	East Asia & Pacific	Lower middle income

(continued)

Table 1.2 (continued)

Country code	Short name	Region	Income group
VIR	Virgin Islands	Latin America & Caribbean	High income: nonOECD
WBG	West Bank and Gaza	Middle East & North Africa	Lower middle income
YEM	Yemen	Middle East & North Africa	Lower middle income
ZMB	Zambia	Sub-Saharan Africa	Lower middle income
ZWE	Zimbabwe	Sub-Saharan Africa	Low income

Table 1.3 Some selected countries/regions with large populations

Brazil	BRA
China	CHN
European Union	EUU
India	IND
Russian Federation	RUS
United States	USA
World	WLD

Table 1.4 Abbreviations for the different global regions

ECS	Europe & central Asia
LCN	Latin America & Carribean
MEA	Middle East & North Africa
NAC	North America
OED	OECD
RUS	Russia
SAS	South Asia
SSF	Sub-Saharan Africa
WLD	World average

to first analyze how good the cities are with respect to a number of different aspects. The cities then made a priority list over what aspects were most important. In Santiago de Compostela for instance lights were most important, while in Eskilstuna, Stoke on Trent, and several of the other cities it was renovation of buildings. Thereafter, the potential for improvements was determined for the most important aspects and presented in city energy development plans. The partners were Eskilstuna energy and environment (coordinator), Mälardalen University, Eskilstuna city, Hamburg University in Germany, Stoke on Trent in the UK, Santiago de Compostela in Spain, Jyväskylä and Turku cities, Turku University of Science in Finland, Siemens in France, Technical University in Vienna, Austria, Copenhagen University in Denmark, Technical University in Delft, Netherland, Tartu city in Estonia, Smartta in Lithuania and University of Ljubljana in Slovenia

Table 1.5 Energy efficiency indicators. From EU FP7 PLEEC project

Domains	Key fields	Indicators	Unit
Green buildings and land use	Renovation	Share of annual thermal renovations	%
		Share of dwellings in low-energy buildings	%
	Building Technology	Share of private low energy buildings	%
		Share of public low energy buildings	%
		Annual heating demand of a new dwelling in low-energy building	kWh/m²/yr
		Annual heating and cooling demand in a new low-energy public building	kWh/m²/yr
	Spatial structure and Land-use	Population density (admin. area)	hab/km²
		Population density (settled. area)	hab/km²
		Share of detached houses	%
Mobility and transport	Public transport	Transport performance in public transport	km/pass/year
		Energy demand in public transport	MWh/year
		CO2 emissions in public transport Cost of a monthly ticket for transport	Tons/Year EUR
	Motorized private transport	Transport performance in motorized private transport	km/pass/year
		Energy demand in motorized private transport	MWh/year
		CO2 emissions in motorized private transport	Tons/Year
		Cost of petrol	EUR/Liter
		Parking fee	EUR/Hour
		Level of motorization	Cars/Cap
	Pedestrian traffic and cycling	Transport performance in bicycle transport	km/pass/year
		Transport performance in pedestrian transport	km/pass/year
		Length of bicycle network per inhabitant	Meters/Cap
	Transport of goods	Transport performance in transport of goods	Kms/Cap
		Energy demand in transport of goods	MWh/year
		CO2 emissions in transport of goods	Tons/Year
Technical Infrastructure	Waste. water and sewage management	Waste generation Waste generation per capita	Tons/Year Tons/Year
		Recycling of waste	%
		Waste collection fee Share of smart-meters	EUR/kg %
	Electric power grids	SAIFI	Outages/Cust
	Heating and cooling grids	SAIDI Share of district heating	Hours/Cust %
	Public lighting	Share of energy efficient lamps	%

(continued)

Table 1.5 (continued)

Domains	Key fields	Indicators	Unit
Production and Consumption	All Sectors	Total Energy demand Without transportation	MWh/year
	Industry and commerce	Energy demand in Industry sector CO2 emissions in industry	MWh/year Tons/Year
		Share of companies with energy management	%
	Private and public services	Energy demand in service sector	MWh/year
		CO2 emissions in service sector Energy demand in private households CO2 emissions in private households	Tons/Year MWh/year Tons/Year
	Consumers/ Private Households	Share of household income spent on petrol	%
		Share of household income spent on electricity	%
	All Energy Supply + Imports	Energy Supply – All	MWh/year
		Energy Imports Energy supply – solid fuels	MWh/year MWh/year
		Energy supply – gas	MWh/year
	Fossil and nuclear energy	Energy supply – crude oil and petroleum products	MWh/year
		Energy supply nuclear	MWh/year
		Electricity tariff – traditional mix	EUR/kWh
Energy Supply	Renewable energy	Energy Supply – All renewable	MWh/year
		Energy supply – wind Energy Supply – Solar	MWh/year MWh/year
		Energy supply – biomass	MWh/year
		Energy supply – hydropower Energy supply – tide, wave, ocean	MWh/year MWh/year
		Energy supply – Geothermal including heat pump	MWh/year
		Energy supply – waste	MWh/year
		Electricity tariff – renewables mix	EUR/kWh

and Rous University in Bulgaria. The project integrated technical, behavior and organizational aspects, and developed a tool for analysis which was tested towards the six cities.

The first angle was the technical aspect. In Table 1.5 we see the five different domains and the 18 key fields identified from the technical perspective. The domains are

1. Green buildings and land use,
2. Mobility and transport,
3. Technical infrastructure,
4. Production and consumption and
5. Energy supply.

One or more indicators and the way in which these are measured are also identified for each key field in the table.

In Allingsås, in western Sweden, the brick walls were totally cracked due to the impact of SO2 in the air. Therefore, the task was to either take the apartment houses down or do an extensive rebuild. Since the body was made out of concrete that was still in good shape, the houses were rebuilt by removing all walls that were not concrete and replacing them with 30 cm polyurethane or 40 cm glass wool insulation. Big blocks, three stories high and 2.4 m wide were mounted that included windows, ventilation and the like. In this way a quick replacement and passive house standard in the apartments were achieved. This means principally that there is no need for external heating except what is emitted from appliances and body heat. District heating is used to heat air and hot water. The windows were also replaced with well insulated argon-filled panes of glass. Ingoing and outgoing air was heat exchanged, thereby reducing the demand to heat incoming ventilation air. Still the cost was quite high— some 120 000 €/apartment, although much of this cost was related to installing elevators and handicap-friendly toilets in addition to the energy improvements. The amount related to the energy improvements is in the range 130–570 €/m^2 depending on how the different costs are divided. Still, the improvement will pay off in less than 20 years according to Hans Eek at passive house center in Allingsås, at least in relation to building a completely new building. The energy reduction was 62–85% depending on how it was counted.

In other cities such as Eskilstuna, also in mid Sweden, other actions were implemented. In one case plaster at the surface coating was refurbished to take away visible cracks, and then painted with a paint that claimed to give some extra heat insulation through addition of porous ceramic particles. The direct improvement of this action was difficult to measure as three out of six refurbished houses showed improvements in the range 4–10%, while the other three showed no improvement or even a slightly increased energy demand. The reason is probably due to other factors made simultaneously outside of control, like change in individual behavior. It shall be noted that hot water was included in the heat demand and a shift was made by going from measuring a whole group of buildings to only two at a time. After this, measurement was also made in every 3rd apartment, thereby giving the possibility to control the temperature by feeding more or less district heated water. This was done 1–2 years before, and the effect of having better control was seen to be in the range 15–20%, but may also have appeared after the new measures. The overall reduction after doing the refurbished surface coating, implementing better control and replacing old heat pumps recovering heat from exhaust air was 34% on average for the six apartment buildings. The cost for the overall actions was 28€/m^2.

In a neighbouring area in Eskilstuna a renovation was done for the same type of houses with plaster coating. Here, 5 cm insulation was applied at the plaster and 15 cm insulation at the attic. Also, two glass windows were complemented with one extra. The cost for this renovation was 65 €/m^2 while the energy savings after 1 year averaged 56.5% with respect to heat. All these energy savings only account for heat demand, but in reality electricity demand may be changing because some tenants may add electric heating directly or indirectly by appliances or electric radiators.

A forth example of renovation was made at Stoke on Trent in the UK. Here, plastic was filled between outer walls and inner walls or complemented with external insulation, approximately 12 cm. The windows were also improved. The cost for this was estimated at 130 €/m^2 and the energy savings estimated to be 56%. Stoke

Table 1.6 Investment cost versus energy savings per m² building area in apartment houses

	Investment €/m²	Savings kWh/m², y (%)
Allingsås passive house standard	133–570	62–85
Lagersberg advanced renovation	65	56.5
Råbergstorp control + paint	28	34
Stoke on Trent	130	56

From EU PLEEC project report D3.4

Table 1.7 Pay-back time (PBT) as years respectively as a function of life expectancy of the action taken

Area	Saved energy (kWh/m², y)	Saved costs (€/m², y)	PBT (years)	Life expectancy (years)	PBT/life expectancy
		0.05 0.07	0.05 0.07		0.05 0.07
Allingsås 1	168	8.4 11.8	15.8 11.3	50	32% 23%
Allingsås 2	168	8.4 11.8	68 48	50	136% 96%
Lagersberg	113	5.7 7.9	11.5 8.2	30	38% 27%
Råbergstorp	68	3.4 4.8	8.2 5.8	20	41% 29%
Stoke on Trent	112	5.6 7.8	23 16.7	30	77% 56%

has a significantly milder climate, but on the other hand the standard before improvement was very low from an energy efficiency perspective, as there was principally no insulation at all before the refurbishment!

A comparison between different levels of renovation is seen in Table 1.6 (Campillo et al. 2016).

Still it is not only investment cost as such and the energy saving effect that is of interest for a city planner. The question is also how long the renovation action will last until a new one is needed. In Table 1.7 we made some calculations for the pay-back time for renovations of different kinds. Here, it actually makes sense to renovate to passive house standard if we can use the lower renovation figure, 133 €/m², while the higher 570 €/m² still seems too high compared to other actions. On the other hand, the renovation to passive house standard could only cost half of what the cost would be to take down the old and build completely new buildings instead, as was the case in Allingsås! How energy actions are related to other actions like making a house handicap-friendly or just look nicer is something that is not self-evident; as can be seen for the very big difference between what is considered to be the renovation cost addressing energy issues made by the passive house centre (the lower) and an external consultant (the higher). In Table 1.7 we assumed starting with 200 kWh/m²,y and the two different energy costs 0.05 and 0.07 €/kWh. For the Allingsås case we have two different figures for renovation as well (133 resp 570 €/m²). We also added another renovation case in the PLEEC project in Stoke on Trent, where plastic beads were filled between inner and outer walls and new windows as well as heat recovery on ventilation air were installed.

Energy behaviour by the customers was evaluated in parallel by both measuring individual use of electricity and asking questions about the habits.

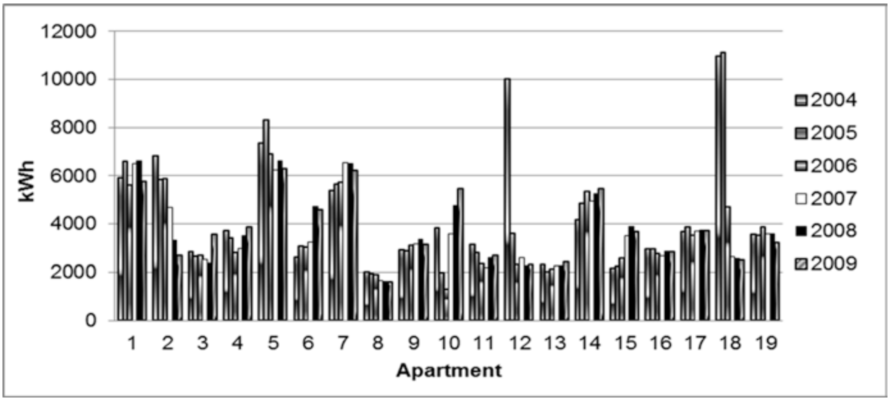

Fig. 1.1 Comparison between consumption of electricity in different households with two persons in each over 6 years, 2004–2009

Here, we can see a big difference between different tenants. In a study in Vasteras we measured heat and electricity consumption in 24 apartments 64, 80 or 96 m^2 in size. It turned out that there were two adults and no children living in all apartments. Still, the difference between the individual apartments was a factor of at least five between the highest and lowest consumers. It was not easy to determine any single component or appliance that differed significantly between the high and low consumers, but there was a significant difference between the household total incomes. The high consumers generally had higher income. It was not a single appliance but many more in those households. The consumption during several years is seen for 19 of the 24 customers, those that replied to the questionnaire, in Fig. 1.1. In Fig. 1.2 we see for the first 2 years of the study, 2005 and 2006, that the difference between similar tenants and apartments is up to 10 times! (Vassileva 2012) and Vassileva et al. (2012).

In Fig. 1.2 we see that for these 2 years apartments number 8 and 16 consume 1000 kWh/year, while apartments 10, 14 and 15 are in the range 5000–7000. There is no single factor showing the cause of this difference aside from the household total income that is significantly higher in apartments where a lot of energy is used. In apartment 14 we also see a strong decrease from 2005 to 2006, which was in this case due to tenants moving out and new persons coming in with different habits.

Design of new energy efficient buildings was also evaluated although the renovation of old buildings has a higher priority as most existing buildings will still be in use 50 years from now, and will still be the majority of the buildings.

An example of a detached house is the one designed by Bengt Stridh, the most prominent PV cell and sun power blogger in Sweden. Here, passive house standard is combined with both PV cells, solar power, hot water storage and heat pump. A wood stove is also installed as the reserve. See Fig. 1.3.

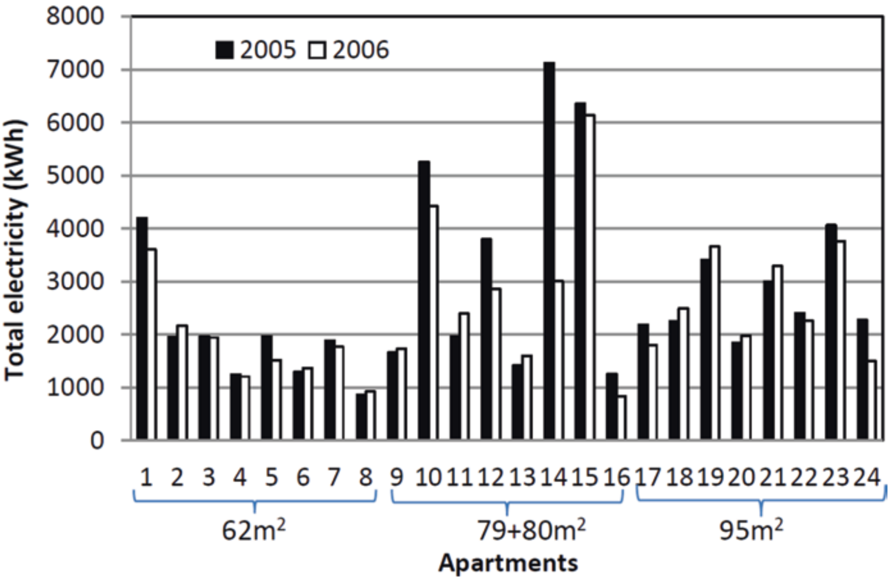

Fig. 1.2 Electricity consumption in apartments with two adults during 2005–2006 in apartments with different size

Fig. 1.3 An example of an energy efficient building in Vasteras, Sweden. In the photo Bengt Stridh and two Indian PV cell researchers from the Indian Institute of Technology work on new types of PV cell materials

1.4 Economy

In this chapter we cover different aspects of the importance for economic sustainability, which is normally also very important for sustainability in general.

1.4.1 Taxes and GINI-Numbers

Sometimes taxes are seen as something extremely negative that should be kept at a minimum. On the other hand a society taking care of its population creates a stable society which can develop economy so that no one is kept in poverty. This is something that can be seen when analyzing how the GINI-index correlates to general stability and happiness in the countries. Generally, people feel happy in countries where the GINI-index is low, that is the ratio between the very rich and the very poor is low. The index normally used to follow development in a country is the gross national product (GNP) or gross national income (GNI). Calculating the total trading of all goods and services in a country and dividing it by the total number of inhabitants gives GNP/capita. A problem here is that some services are not included, such as improvements of living conditions that do not cost money, like better web-apps (that may be free), better electronics (that have a lower price per unit when purchased due to better technology), more efficient food production (lower cost per kg reduces the GNP, although obviously better for society at least from an economic perspective).

In Fig. 1.4 we see the tax revenues in different regions. The explanation of the abbreviations for the different regions is given in Sect. 1.2. We can see that tax revenues are higher in the EU and central Europe compared to most other regions, and if

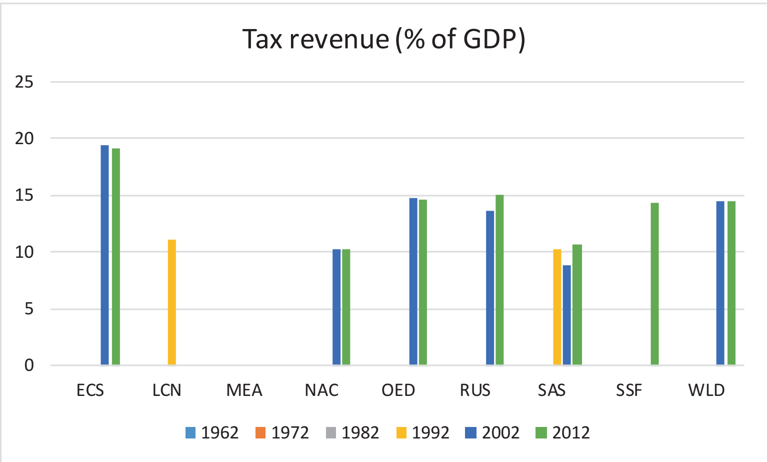

Fig. 1.4 Tax revenues as % of GDP (GNP) in different parts of the world

we had separated different countries we could see that North and Western Europe have significantly higher values than the average, while Eastern Europe has significantly lower levels. We also know these high-tax countries in general have lower GINI-values and better economies. In North and Central America the tax-level is lower than in Northern and Western Europe. The average economy as GNP/capita is at the same level but the GINI-index is significantly higher, since the difference between rich and poor is significant, especially in the US.

1.4.2 Inflation

Another important factor is inflation. Generally, countries strive for approximately 2% inflation per year nowadays. This is to make it possible to have some money to distribute for new reforms. During the 1960s this level was normal, while it generally increased to around 10% at the end of the 1970s until the 1990s in many developed economies. In the last 10 years on the other hand inflation has been reduced to just 0–1%, and the interest rate now is less than 0% in many countries. This should give the economies in the developed countries a push, but has generally not, although in some countries the economy has been increasing. This is against present economic theory. On the other hand, we have seen a very strong development in Eastern Asia, and especially in China, where economic growth has been in the range 7–13% for the last 20 years. This has given rise to a strong development of economic conditions in the big cities along the east coast. Simultaneously, energy use—especially electric power—has increased dramatically. Electric power was 650 TWh/y in 1986 and now it is in the range of 4000 TWh/y. This increase is mostly through increased use of coal which has caused tremendous air pollution. As industries developed the rivers were also polluted, and now this is having a strong negative impact on people's health. The leaders of the country see the problem and demand actions, but the trade-off between economic development and reduced emission and climate effect is challenging. If the economic development stops people might think of a new revolution. Another negative aspect has been strong corruption negatively affecting this tricky balance. Thus, President Xi and his colleagues have started a strong fight against corruption which has negatively affected economic development short term, but hopefully will give positive effects long term both on economic growth and environmental aspects. The economic development in China has driven the development in most countries in the world for the last 15 years, but has also caused an imbalance between available resources, consumption and environmental impact.

In India we see a similar development, although not as strong yet, with less of an increase in coal usage. On the other hand, one new coal mine is opened every month, and the climate effect will increase substantially over the next few years.

In Eastern Europe we still see little awareness of climate issues around fossil fuels. Unfortunately, this is also the case in many other countries. Therefore, it was positive to see that 195 countries signed the agreement on reduction of climate gases in December 2015 in Paris. Here, most countries state how much they believe they

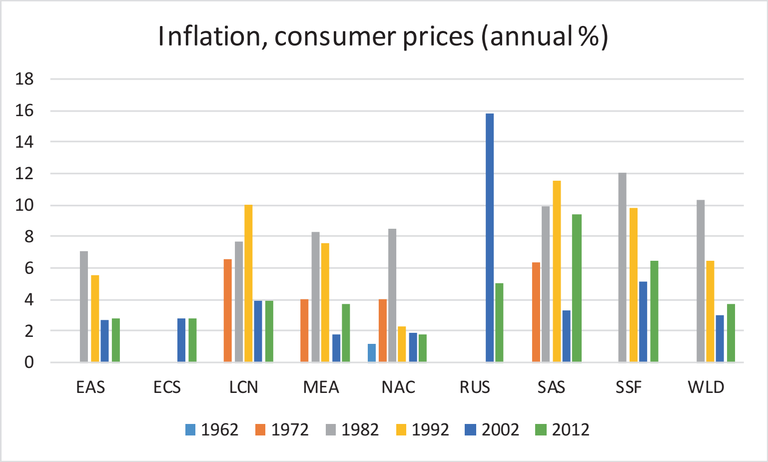

Fig. 1.5 Annual inflation and increase of consumer prices in different regions

can reduce their emissions by 2035 and 2050. The goal is to keep the temperature increase below 1.5 °C, although the commitments indicate a possible temperature increase of 2.5–3 °C by 2100. The developing countries also demand the richer countries to pay for their actions for mitigation. Still, it is very positive that so many countries now agree on a necessity to act. The request is to supply 100 000 M$/y for these climate actions from the rich countries, but the distribution of cost and who should get what is unclear.

We still do not know if this will drive inflation, but there is some probability for it.

In Fig. 1.5 we see how inflation developed since 1962. Since Europe (including Central Asia) and Russia (excluding states in the Soviet Union not belonging to Russia today) have changed structure, there is only comparable data for the last 10–15 years. Still, the trend was the same in East Asia, the EU and North America. Annual inflation of the order of magnitude 7–10% during the 1980s and 1990s has decreased to less than or equal to 2% in 2015. In Russia the inflation boomed during the 1990s at ~15% but now has decreased to around 5%. In Latin America it has also stabilized but at a slightly higher level than in Western Europe and North America, some 4%, which is also the case for the Middle East and North Africa. In South Asia, primarily India, the inflation rate was still high at 9% and in Africa South of the Sahara somewhere around 6% in 2012. However, the inflation rate is significantly lower than previously. One factor reducing the inflation rate is that oil price has been reduced from levels around 100–120 $/bl since 2000 to around 45–50 $/bl when this was written in early 2016. This has reduced the cost for energy in most countries, but also caused problems to government finances in countries like Russia and Venezuela, where income from sales of oil and gas have been major sources of tax income. Astonishingly, Saudi-Arabia and Norway are also suffering quite hard from this oil price reduction; during 2015 some 30 000 people in Norway's oil industry were laid off, and in Saudi-Arabia the current national budget is strongly under financed.

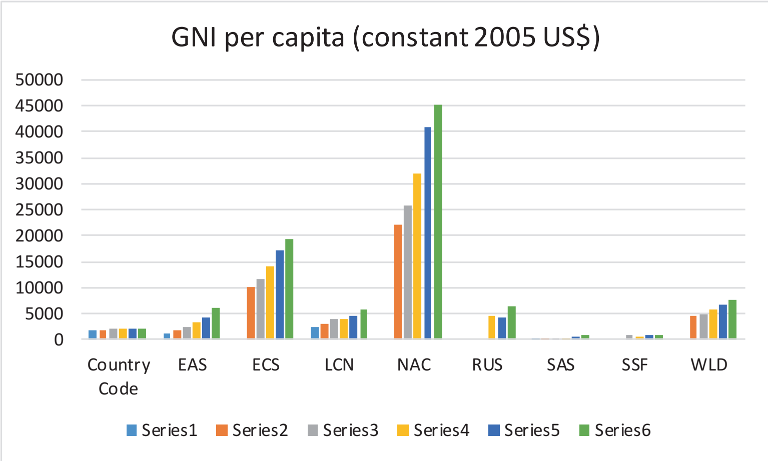

Fig. 1.6 GNI per capita

In 2015 use of fossil fuels stabilized and did not increase as earlier, and thereby caused a slight surplus of oil and gas, and especially coal, on the global market. From an environmental perspective this might be negative short term, since alternative energy gets tougher competition, if no regulatory actions are taken.

1.4.3 GNI

We have already talked about GNP, Gross National Product. Another measure is GNI, Gross National Income (Fig. 1.6)

In Fig. 1.7 we see the development of GNI from 1962 to 2012. As seen it has increased a lot in all regions, although less in Africa South of the Sahara and Russia compared to the other regions. The increase has been especially dramatic in East Asia. In absolute terms we see that East Asia, Europe and central Asia and North America have almost the same level of GNI 2012, while the difference was huge in 1972. In Latin America the increase has been very strong, and also doubled in Europe and central Asia and North America during these 50 years in 2005 $ value.

In India many people are much better off, although the GNI per capita is still on a much lower level than in, e.g. China. In reality the level is more like in Africa South of the Sahara for the vast majority.

The increase has probably been significant during the last few years, but the delay in statistical reports obscures it presently. In countries like Nigeria we also have revisions of GNP and GNI because a lot of business is not seen in the real figures. This especially includes some IT-related activities. Thus, according to revised figures Nigeria claims to be a bigger economy than South Africa since 2014, although it is significantly lower in the official figures of the World Bank.

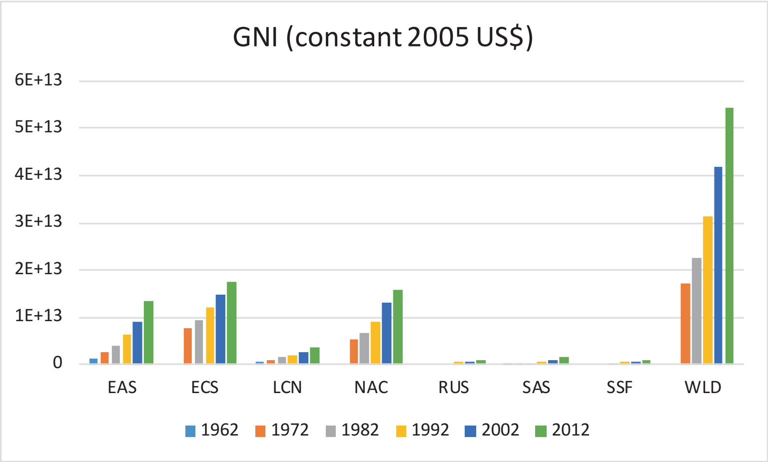

Fig. 1.7 GNI, Gross National Income during 1962–2012 for different regions

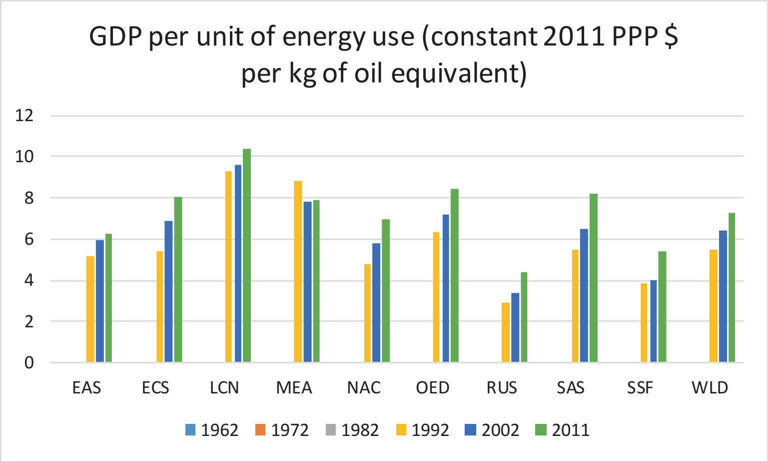

Fig. 1.8 GDP per unit energy used

In Fig. 1.8 we see the GDP as a function of energy used. Russia sticks out a lot as GDP in relation to energy use is low. The reason is the historical system where the economy was centrally controlled, and the price for energy could be only 1/3 of the production cost, which has not been a sustainable situation.

In Fig. 1.9 we see GDP per capita development. It is obvious that it has increased dramatically in East Asia, Europe and North America, but less in the other regions. Once the economic development was only in developed countries, but now it is even stronger especially in China, India and many surrounding countries. Still, what should be noticed is the difference between different groups inside these countries

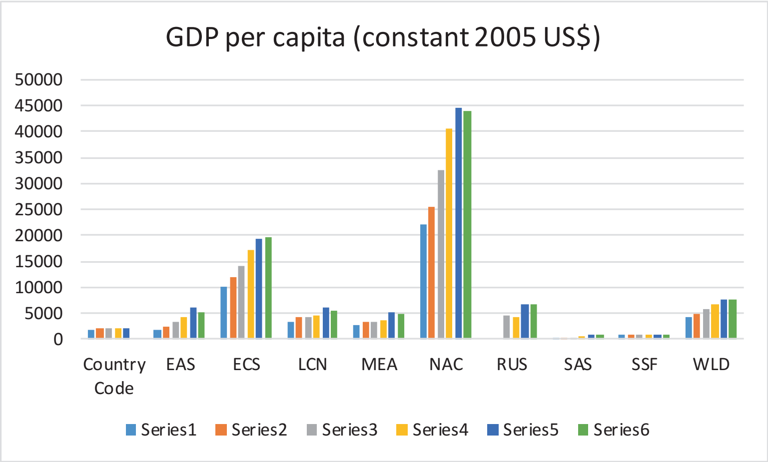

Fig. 1.9 GDP per capita

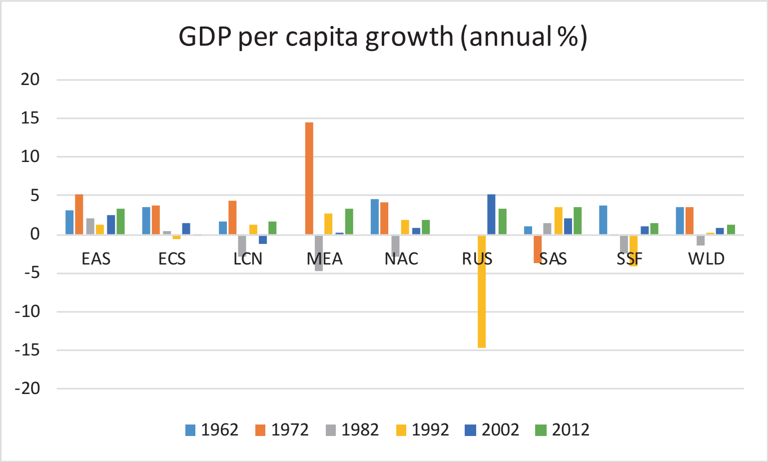

Fig. 1.10 GDP growth per capita and year in %

and others. We see strong development in Nigeria, which was able to override South Africa as Africa's largest economy last year (probably!). Still, it is not easy to get correct data for Nigeria since some new activities like IT-solutions are not counted. In Fig. 1.9 we can see that most regions have grown with respect to GDP per capita and year for the last 10 years, with the exception of the EU, where the economics have suffered a lot recently. The crisis in Greece, Italy, Portugal and Spain have given a down turn in these countries economic development, and this has not been compensated in full from reasonable development in Germany, Sweden, the UK and some other countries (Figs. 1.10, 1.11, and 1.12).

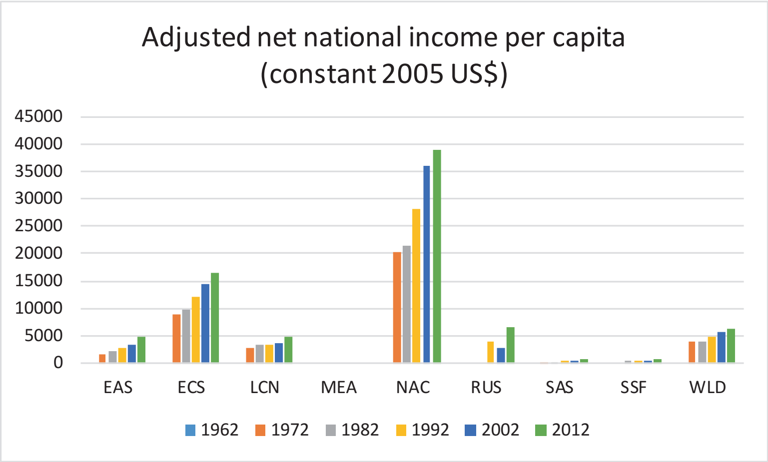

Fig. 1.11 Adjusted net national income per capita

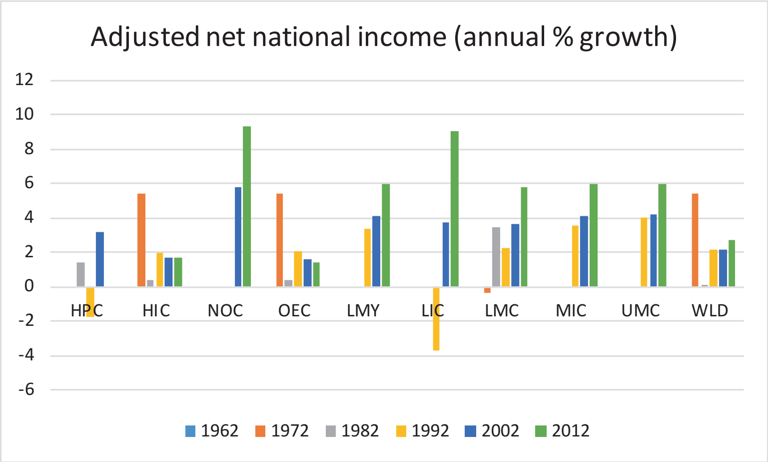

Fig. 1.12 Annual growth of net national income in different regions

Adjusted national incomes for specific groups of countries are seen in Fig. 1.13. We can see that heavily indebted countries (HPC) have very low adjusted national income per capita while high income countries (HIC) have very high. Lower middle income (LMY), lower income (LIC), middle income (MIC) and upper middle income all show a relatively strong increase over the years. The annual increase is still a higher % increase in the latter than in the HIC countries.

The positive conclusion is that we can see a relatively strong development of living standard over the last 50 years.

In Fig. 1.14 we see GNI per capita in some specific, important countries. Here, we see that the US has the highest before the EU. China has the highest increase during

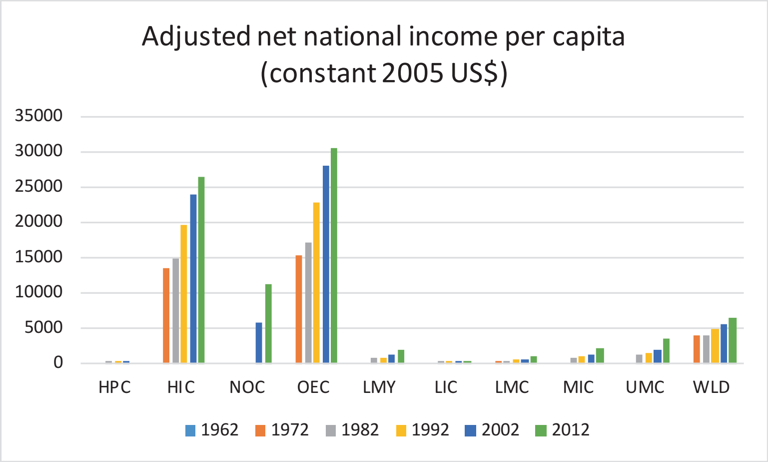

Fig. 1.13 Adjusted national income per capita resp increase per year in %

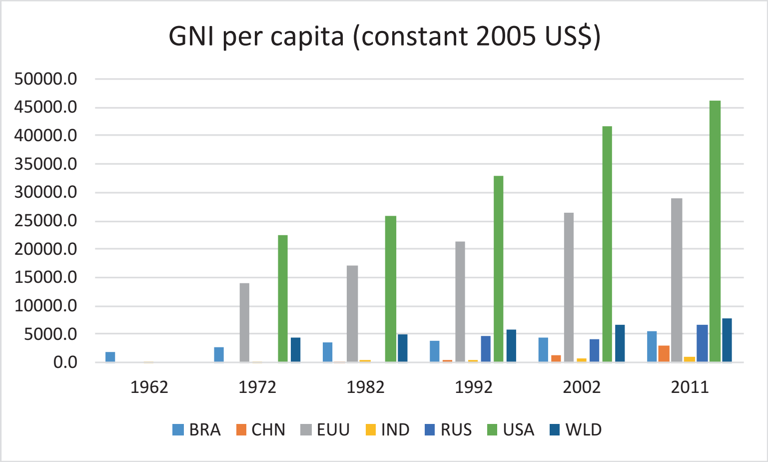

Fig. 1.14 GNI in some important countries

Table 1.8 GNI per capita in some population rich countries and regions

Country code	1962	1972	1982	1992	2002	2011
BRA	1886.6	2797.0	3671.1	3837.5	4301.7	5636.9
CHN			245.1	534.1	1189.3	3093.5
EUU		14030.4	16959.5	21246.2	26398.0	28931.8
IND	233.0	262.6	304.9	406.9	605.0	1110.0
RUS				4556.4	4223.6	6563.5
USA		22504.5	25976.3	32791.7	41738.0	46090.3
WLD		4451.5	4933.0	5731.7	6683.7	7737.3

the last 30 years. Russia has the lowest development since 1992. India is developing relatively fast, but is still approximately four times lower than China. Brazil has developed, but not as fast as China and India, and started from a higher level.

In Table 1.8 we see GNI per capita in US$ (2005 value) in important countries and regions. What we can see here is a huge difference between India and the US. On the other hand many Indians, a few 100 million, have similar economic conditions as average people in the US, while a tenth of millions in the US have very poor conditions. This is a problem when comparing nations and regions; we only see average values.

1.5 Different Cultures

We all suspect that there are different cultures in different countries, or even between different groups in a single country. In "Cultures and organizations" Hofstede and Hofstede (2005) tried to quantify different aspects of the culture in the same company (IBM) in different countries. He studied the differences between managers, secretaries and sales people at local IBM companies in 50 countries and 3 regions. The people had similar work tasks, thus giving opportunity to study how their behavior and attitudes differed primarily due to local customs.

He organized the attitudes into four different areas: Power distance, Individualistic/collectivistic society, Uncertainty avoidance and Masculinity/femininity.

1. High power distance represents a large difference in status between managers and employees, or a very hierarchical society. The manager has strong power when power distance is high.
2. Individualistic society is where it is considered positive to treat everyone in a fair way, independent of personal relations, and where it is positive to argue for your own ideas. This is contrary to collectivistic societies, where it is natural to, e.g. promote a relative before a more knowledgeable "foreigner", as keeping the group strong is the most important issue. "Bribing" may be considered as a norm.
3. Strong uncertainty avoidance means that you want strict rules and procedures, governing your life. Low uncertainty avoidance means that you do not follow written rules but try to find ways around them.
4. Strong masculinity means that you prefer solving problems with a battle and being best is the norm, while feminine societies solve problems by talking and compromises and being good enough is the norm, as well as being appreciated by your colleagues is a goal.

Later he added a fifth category after doing an investigation in China. This was a long term perspective on life or a short term perspective. In East Asia people often have a very long term perspective which means decades, while in e.g. Western Africa the perspective may be weeks instead (very short term planning). A Japanese company may show red figures for a number of years if the investment is consid-

Table 1.9 Index according to Hofstede study on cultural differences

	Power distance	Individualism	Uncertainty avoidance	Masculinity	Long term orientation
Argentina	49	46	86	56	
Arab countries	80	38	68	53	
Australia	36	**90**	51	61	31
Austria	**11**	55	70	**79**	
Belgium	65	75	94	54	
Brazil	69	38	76	49	65
Canada	39	80	48	52	**23**
Chile	63	23	86	28	
Colombia	67	**13**	80	64	
Costa Rica	35	**15**	86	**21**	
Denmark	**18**	74	**23**	**16**	
East Africa	64	27	52	41	
Ecuador	78	**8**	67	63	
Finland	33	63	59	26	
France	68	71	86	43	
Germany	35	67	65	66	31
Great Britain	35	**89**	35	66	25
Greece	60	35	**112**	57	
Guatemala	95	**6**	101	37	
Hong Kong	68	25	29	57	96
India	77	48	40	56	61
Indonesia	78	**14**	48	46	
Iran	58	41	59	43	
Ireland	28	70	35	68	
Israel	**13**	54	81	47	
Italy	50	76	75	70	
Jamaica	45	39	**13**	68	
Japan	54	46	92	**95**	80
Malaysia	**104**	26	36	50	
Mexico	81	30	82	69	
Netherlands	38	80	53	**14**	44
New Zeeland	**22**	79	49	58	30
Norway	31	69	50	**8**	
Panama	95	**11**	86	44	
Pakistan	55	**14**	70	50	**0**
Peru	64	**16**	87	42	
Philippines	94	32	44	64	**19**
Portugal	63	27	**104**	31	
Salvador	66	**19**	94	40	
South Africa	49	65	49	63	
South Korea	60	**18**	85	39	75
Spain	57	51	86	42	
Singapore	74	20	**8**	48	48

(continued)

Table 1.9 (continued)

Sweden	31	71	29	5	33
Switzerland	34	68	58	70	
Taiwan	58	17	69	45	87
Thailand	64	20	64	34	56
Turkey	66	37	85	45	
Uruguay	61	36	100	38	
USA	40	91	46	62	29
Venezuela	81	12	76	73	
West Africa	77	20	54	46	
Yugoslavia	76	27	88	21	
China					118
Bangladesh					40
Poland					32
Zimbabwe					25
Nigeria					16

ered interesting long term, something hardly possible in many West European countries or the US.

In Table 1.9 we can see how the different factors varied between different countries in Hofstede's investigation. We cannot make strict statements on how single persons are in relation to these figures, and as already mentioned there may be significant differences between different groups in a specific country, such as very religious groups etc. Still, it gives an indication of how different perspectives on life can be. It is easier to develop a sustainable society if people have a long term perspective on life, and then include resource and environmental aspects. All factors are still important when it comes to implementing strict rules and measures to achieve a sustainable society. In countries with heavy bribing for instance, you can buy yourself away from implementing principally strict environmental rules. In China we see a very strong negative impact on the environment especially in the big cities although the culture has a long term perspective, which shows that other factors seem to be more important at least short term.

What we can see is that individualism dominates in Anglosaxian and northern European countries, while collectivism is the most common globally. This makes it problematic to get global agreements on common rules as the western view is that you shall employ someone on their specific "technical" competence, while in most countries you should favor people belonging to your own group for employment. Generally, we see a trend in areas with economic development to become more individualistic, while there are religious groups driving in the opposite way, even causing armed conflicts. In the UN we see a drive that everyone should have the same rights and possibilities, which is more the Anglo-Saxon way of seeing things. This means that females should have the same rights as males, which is still problematic in some cultures.

The "feminine" vs "masculine" aspects give the difference between societies where the society takes care of the population and societies where everyone should take care of themselves. This is not at all following individualistic vs collectivistic cultures. In Northern Europe strong individualism follows a demand for society to take care of their citizens, which is a “feminine” way of seeing things; while in many countries like the US or China everyone is supposed to take care of themselves, or by the close family-group. Generous rich people are supposed to give contributions to help the poor, but not society as such.

In societies with high structural organization, rules govern like in Germany, while in other countries you have a more easy-going attitude like in the UK. In Sweden the hierarchy between managers and employees is very low and everyone has a say in many decisions, while countries like France, China and South East Asia normally have much stricter hierarchies where the manager often makes the decisions themselves. This of course not only presents quite different conditions for doing business, but also for attitudes towards authorities in general, for good and bad.

The fifth aspect—long term or short term perspectives—should have a strong impact on sustainability. In countries with very short term perspectives, like West Africa, decisions are often made with a time horizon of days, while in long term perspective countries like East Asia you principally have time horizons of decades, although overrun in many ways during last 30 years in, e.g. China. Here, environmental pollution has become a major problem because nature is being used in a negative way from a sustainability perspective. In West Africa on the other hand the relatively low investment volume has led to a less severe impact from a quantitative perspective, although, e.g. mining has caused huge problems locally with metals leaking out. So we cannot see what could be expected in reality from principal cultural differences in this case!

This discussion shows that cultural differences have to be considered when we develop common global regulatory systems. Argumentations may be different in different countries depending on regional conditions. Still, by defining what the overall goal should be and what direction to take should make it possible to create a reasonable common picture of what to strive for. The Paris agreement between 195 countries in December 2015 on <2 °C global warming goal shows this. From this each country shall make their own plans for how to implement—what actions to take, what instruments to use to drive implementations etc.

Fig. 1.15 shows a grouping of populations with respect to “traditional” versus “secular” values on y-axis and economic conditions expressed as going from “survival” towards “self-expressing yourself” on the x-axis. What we can see is that northern-western Europeans in “protestant Europe” are highly “secular” and strive for “self-expressing” themselves (=individualistic perspective), while African-Middle east Islamic populations have “traditional” values and “life is enough as it is” – you should not strive to develop yourself as an individual, but strive for the collective (= collectivistic perspective). In reality this shows very similar characters as in Hofstede’s table, but with different wordings.

To some extent we can say that the culture is developing in the direction of a more individual perspective with general human rights as stated by the UN. On the other hand, we also see trends trying to drive the other direction in some Christian cultures like in the US and in some Islamic cultures.

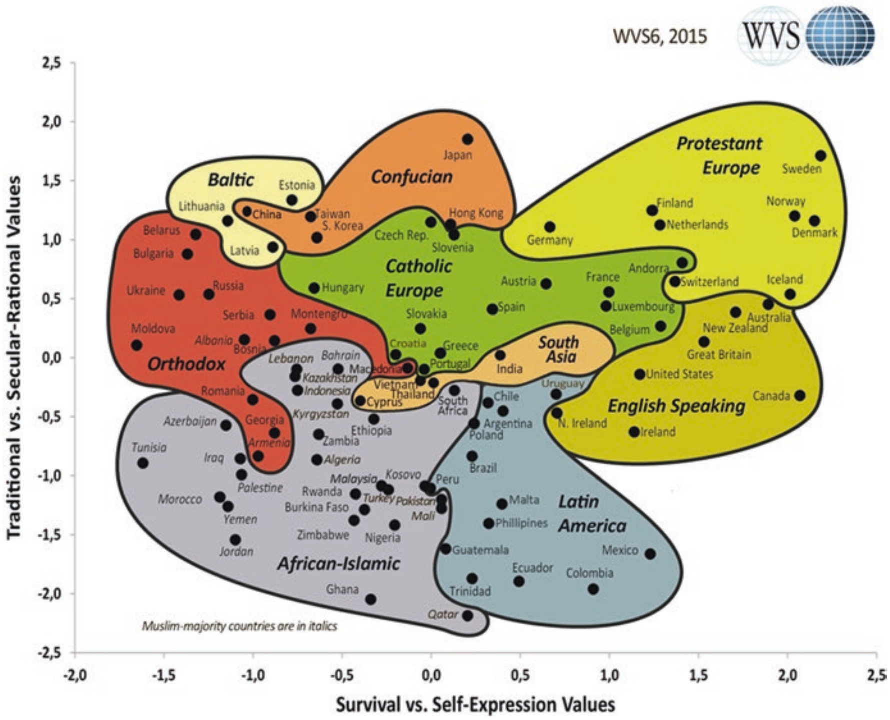

Fig. 1.15 Inglehart-Welzels Cultural map over the countries of the world [www.worldvaluessurvey.org] (2016)

Another obstacle related to culture is corruption, which is covered below.

1.6 Corruption

We have very different cultures in different countries as discussed in the previous section. One way to reflect this is to look at the corruption index in different countries. This raises the question if it is OK to bribe civil servants, officials, customers, politicians etc. or not. In some countries it is part of the normal business environment, while in other countries it is seen as the most negative act you can possibly do, aside from killing someone. In Northern Europe and Northern America you are punished heavily if you engage in bribing, and it is not acceptable even to try to do this, while in many other countries bribing is considered as "normal practice". Still, according to statistics the economic development is normally slowed down in economies accepting of bribing compared to if this is not allowed. We can see that income per capita is lower in corrupt economies according to Figs. 1.16 and 1.17 below, extracted from World Bank development indicators (2016) and Gapminder (2015).

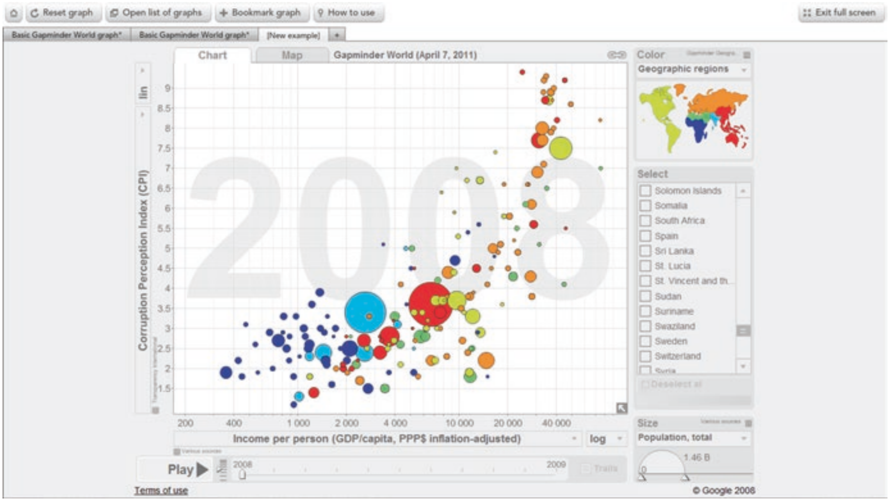

Fig. 1.16 Corruption index vs income 2008. High CPI index means low level of corruption

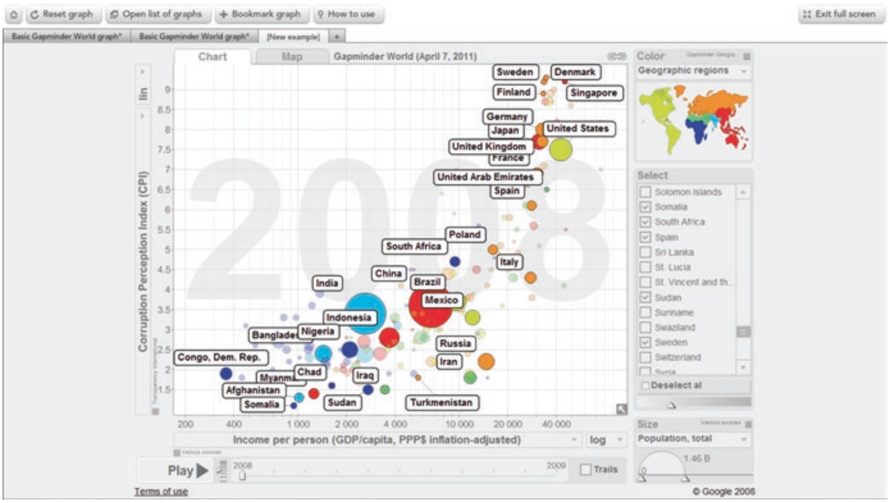

Fig. 1.17 Corruption index for a number of countries. From Gap-minder home page

What we can see is that corruption according to the CPI index is related to buying yourself around a normal purchasing arrangement in competition. It might not be more economic for the one getting the order but often will be very profitable for someone in power in the purchasing activity. That it will not be positive for the companies, the supplier or the buyer, is obvious, as someone has to take the extra cost. This is the reason for the negative effect on economy. Buying yourself around fulfilling high demands also reduces the pressure to develop better products. An example is when industries pay a fee to not need to clean effluents from a factory. This reduces investment cost, but may destroy the down-stream river. Even if the government put up strict demands on industries no one actually needs to follow them by this possibility. In big international corporations, companies often compete internally, and thus drive to have the same conditions in all countries. This has driven environmental improvements in the big international companies in many developing countries, but unfortunately it does not always spread to smaller companies. Governments also normally put much tougher demands on big international companies than they do on local, small companies. This might give competitive advantages short term, but the negative impact on both human health and the environment can be very strong. One example is manufacturing of leather in India, where workers and rivers are hurt. Here, the big companies buy the leather, but do not fully control how it is produced; until the mass media brings it up and customers hesitate to buy the clothes. In this case the companies declare that they follow the regulatory demands, but then buy themselves out from actually following these rules.

By reducing bribing, the economy can be developed in a better way from which everyone principally will benefit, instead of a few individuals who take the money from the system.

On 13 May 2016 there was a meeting on corruption between the UK and the presidents of Nigeria and Afghanistan. The UK prime-minister Cameron was heard saying to the queen that these were two of the most corrupt countries in the world. A reporter heard this and it spread on broadcasts all over the world. The president of Nigeria thus was interviewed later in the evening to give his comment. Instead of trying to say that this was not true he said that the situation was even worse than he had expected when he became president some time ago. Among other things, he mentioned that he had reserved 1.2 billion $ to fight Boko Haram, the Islamic extremist group active in especially northern Nigeria. Then the generals split the money between them instead of using it for the fight. The government is now accusing them and putting one after the other in jail. He hoped that this—when corrupt people are jailed and the money they have stolen brought back to the government—will be a significant contribution to reduce the corruption in Nigeria. If this is not successful he said the country cannot develop in a good way, but if they succeed in reducing the corruption significantly they can really obtain positive development. This type of action to fight corruption is very important and gives hope for the future.

1.7 CO_2 Emissions and Climate Effects

It has been known for many years that CO_2 creates a green-house gas effect. Svante Arrhenius (Svante 2016), the Swedish Nobel prize laureate, tried to get everyone to use more fossil fuels. He said in order to avoid a new ice-age, all fossil fuels known in 1897 should be burnt to increase the global temperature by 3 °C. During the second half of the nineteenth century researchers had come to the conclusion that there had been an ice-age covering large portions of northern Europe, Asia and America. A prediction was made that a new ice-age would come within the next 100s to a few 1000s years.

Around 1960 researchers started to worry more about negative effects of global warming. At the end of the last ice-age there was a back-lash cooling down again of the northern hemisphere during several 1000 years caused by the huge amounts of non-saline water from the melting ice. This stopped the Gulf Stream from reaching northern Norway, and instead it turned close to Spain. This could happen again. Other weather and climate phenomena can also be predicted for a heated earth. This can cause better conditions for agriculture in some areas but worse in others. This then could cause major conflicts which can cause wars. The conflict in Syria with millions of refugees is at least partly a result of a drier climate, which has caused lowered crop production, and from this increased conflicts between different groups.

To avoid too many possible negative effects due to CO_2 emissions society is trying to decrease emissions. At the conference in Paris December 2015 an agreement was made signed by 195 countries, with the aim to keep the temperature increase to a maximum 2 °C rise.

The UN is therefore following the emissions in different countries. In Fig. 1.18 below we see emissions per capita for different regions.

We can see that most regions have a similar level, since oil dominates aside from coal. In Europe there was a decrease in the use of oil and coal as nuclear power expanded while in South Asia (mostly India) the level has increased as oil and coal use increased a lot, whereas biomass has not in the same proportions.

In Fig. 1.19 we see that the emissions from transportation in relation to the total fuel used in combustion varies much more between the regions as well as increases in Europe and central Asia.

It is interesting to note the huge difference between East Asia and South Asia on one side and South and North America on the other side. In China and India collective transportation with higher efficiency than with private cars is very important, while much less used in the Americas, where the private car “is the king”. However,

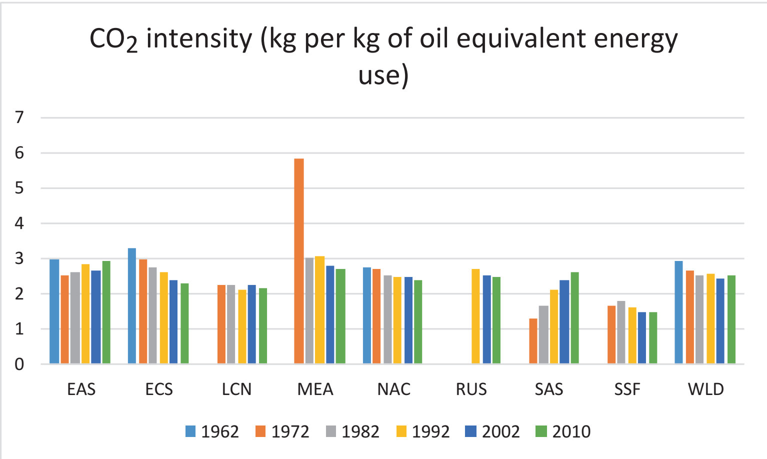

Fig. 1.18 CO_2 emissions per kg of oil equivalent energy used in different regions

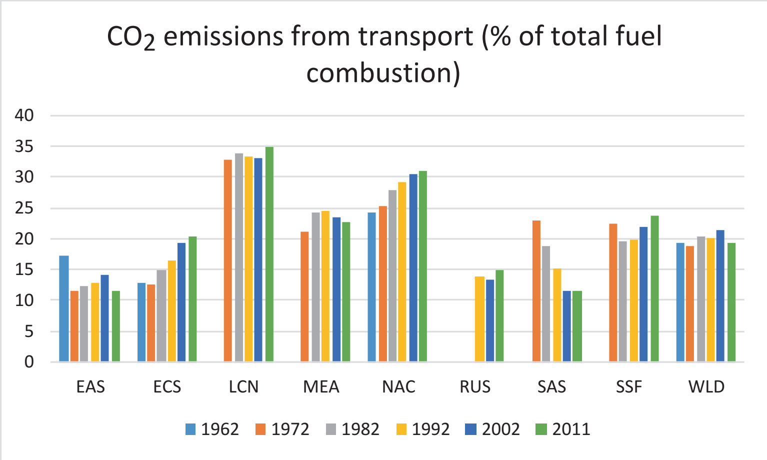

Fig. 1.19 CO_2 emissions from transport in different regions

the relative amount of CO_2 from transportation is due to even faster development of power plants compared to cars, although the number of cars has increased a lot in China and India in the last few decades. In Europe and Central Asia the percentage of CO_2 from transportation has increased both due to more vehicles and a reduced amount of fossil fuel in power generation due to the increase of nuclear, wind and solar power over the last 40 years.

It will be very interesting to see the future developments. In China, electric vehicles have greatly increased. Today we see figures that there are 20–60 million electric bikes/mopedos in China and in Beijing alone there were 80,000 electric vehicles (buses, cars, taxis) at the beginning of 2016; and the amount is increasing fast. Right now 15 stations for replacement of complete battery packages are being built to avoid the need for fast charging of buses and some other heavy vehicles. The reason for electric vehicles is very much related to the dangerous smog in the big cities. People are suffering and getting sick, and by changing to electric vehicles most of the emissions can at least be moved to outside the big cities. Today, electric power is produced in coal fired power plants several hours away from Beijing. A lot of wind and hydro power plants are built as complements, so in the future the amount of coal used for electric power should also be reduced, at least as a percentage of all power produced. Plans presented by the China Academy of Engineering show a plant that should have less than 50% of all power produced from fossil fuels by 2050, although the total power produced should be twice as high as today (Du 2008). If a diesel engine consumes 0.6–0.8 l/10 km it means about 6–8 kWh/10 km. If we use an electric drive we need about 1–1.5 kWh/10 km and no power is needed when the vehicle is cueing and standing still. This means 4–6 times less kWh/10 km. If wind and solar power are used the savings are straight on, while if power is produced in condensing power plants we need some 2.5 times more energy as fuel per kWh electricity produced, assuming 40% efficiency from fuel to electric power.

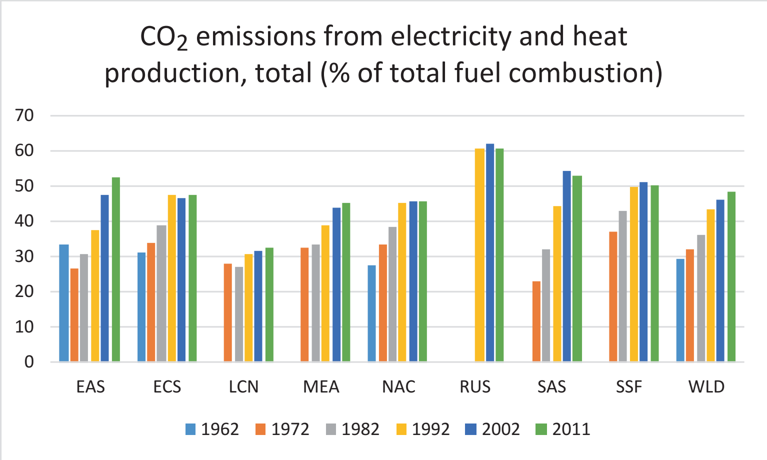

Fig. 1.20 CO_2 emissions from electricity and heat production

Several researchers have conducted LCA studies for biomass and organic waste systems, such as Adler et al. (2007), Cherubini et al.(2009) and Kim and Dale (2005).

In Fig. 1.20 we see that CO_2 emissions associated with electricity and heat production greatly increased in Europe and central Asia, North America and Africa South of the Sahara from 1972–1992, but have slowed down in the last 10–20 years. In East Asia and South Asia it is still increasing but not as fast. Renewable energy and nuclear power are used for a lot of the additional electric power needed, although coal is still increasing as a fuel in both China and India. In many countries natural gas is replacing coal, since the environmental impact is significantly less.

The variation of CO_2 emissions per capita is seen in Fig. 1.21. North America really sticks out here for having almost three times higher levels compared to Europe and China, and approximately 10 times higher than in South Asia and Africa South of the Sahara. The push to reduce fossil fuel has been significant in some states in the US, but more or less non-existing in others. In California, Oregon and some of the North Eastern states there has been a wish to reduce fossil fuels while in, e.g. Texas and other Southern US states and the "coal states" the risks of global warming has actively been diminished by the companies earning money on oil and coal, together with those getting their taxes from these companies. Due to this, we see a divided country and mixed actions. Some states highly promote fracking, to make the US independent of fuel imports, while others promote investments in PV cells and wind power to also reduce climate effects due to CO_2 emissions.

Estimates have been made on the amount of CO_2 emissions per capita that can be allowed and still keep global warming below 2 °C. Some of these indicate in the range of 1.5 ton CO_2 per capita, while some believe we need to reduce to even lower levels. From Fig. 1.21 we see that the global average is around 5 ton CO_2/capita today, while Africa South of the Sahara and India have levels around the acceptable. Still, we see that these countries are those who will increase their emissions most in

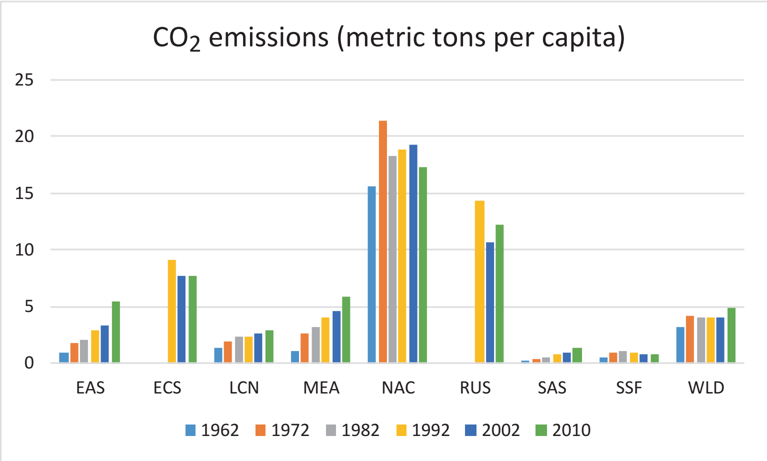

Fig. 1.21 CO_2 emissions per capita in different regions

the future. For Africa, the total amount will increase even further, since the population is predicted to double or more over the next 50–100 years!

In some countries the drive to reduce CO_2 emissions is very strong. In Sweden, the government aims to reduce CO_2 emissions to negligible levels by 2050, and today only around 1/3 of all energy used comes from fossil fuels. Most of this energy is used for transportation, and by introducing electric vehicles and renewable fuels for vehicles this goal is actually realistic. There is also a competing interest from "green parties" in Sweden and Germany to remove not only fossil fuels but also nuclear power. This is probably the biggest threat to reaching the green-house gas emission goals. However, today the business models used normally do not actively try to move loads from times when we have a deficiency of electric power to times when we have a surplus.

At Mälardalen University we did some calculations comparing the production of wind power in Denmark to the consumption of electric power in Sweden and found that if the load is moved 6 h we will remove 70% of the peak power. That is—if we have good economic incentives for moving loads we can eliminate the need for additional peak power capacity by 70%! This is significantly more economic than building capacity perhaps only used a few 100 h per year. Today, there are many different price models, but very few aim at this. To some extent this is due to old habits. To some extent it is because there is still a surplus of peak power capacity, since nuclear and condensing power using fossil fuels are economically competitive as base load capacity. As Germany introduced feed-in tariffs over the last decades wind and solar power was brought into the grid at a high price, which the fossil fueled power plants have not been able to compete with; and thus, such power is taken out of use. Sooner or later we will reach the point where we will have a deficiency in peak power at today's conditions. Then, probably, the new price models with higher prices during hours when the demand is higher than “normal production” will be introduced on a larger scale.

By doing this we would also automatically reduce the amount of CO_2 emissions by utilizing renewable energy instead of fossil fuel in existing plants.

At the same time we see a competition between combined heat and power plants (CHP), where heat is principally the waste from electric power production, and heat pumps using electricity as input, to enhance the quality of heat in the ground or air. In Scandinavia, many CHP plants use biomass as fuel. In Sweden, there is the capacity for production of some 35–40 TWh/y from existing biomass fired CHP plants, but due to regulations and tax-rules only some 10–12 TWh/y is produced. The competition from heat pumps increases the electricity demand while diminishing the demand for the waste heat from CHP plants. This shows how complex the situation can be. In cities with heavy industries we also see lots of waste heat that can be used for heating buildings outside the actual industry. Extra income for the industry can enhance the competitiveness of the industrial operation. It will also reduce the overall CO_2 emissions both in absolute terms and per capita.

In Fig. 1.22 we see the CO_2 emission as ton per capita as a function of GDP per capita. There is a strong correlation for the biggest countries, but a less strong correlation if we look at, e.g. only European countries.

Fig. 1.22 CO_2 emissions per capita versus income per capita as GDP 2011. (Gapminder 2016)

1.8 Science and Communication

The development towards a sustainable society is built on several conditions. One is a direct interest in doing this. This interest is built on knowledge about limited resources, and therefore, a demand to reduce wasting these limited resources and the consequences if we do not drive the development towards sustainability. The knowledge is documented in scientific journals and from here spread to everyone. This includes politicians making the important decisions to develop a frame-work with regulations driving in the right direction. It is therefore also interesting to see how many journals there are covering these subjects. In Fig. 1.23 we see the total number of scientific and technical journal articles published per year.

It is evident that most articles are published in European and American Journals. However, many articles may be authored by researchers in many more countries. In reality the amount of scientific and technical research and journal paper production is increasing in China, India, Iran, Turkey and other countries with a high appreciation of scientific work.

The journal application is one part. Patent applications often come as a complement, and also here we see a high increase in the same countries. In Fig. 1.24 we see patents per region.

It is noticeable that the number of patents increased a lot in North America, China and India, but not in Europe. It is up for discussion if it is because European countries do not believe in patents or if there has been stagnation in European industry. We will see! (Fig. 1.25).

The scientific papers are produced by researchers; we see high numbers in Europe, North America, China and Russia. India is principally not seen in the diagram, but is increasing production and will soon be noticed as well. In Africa

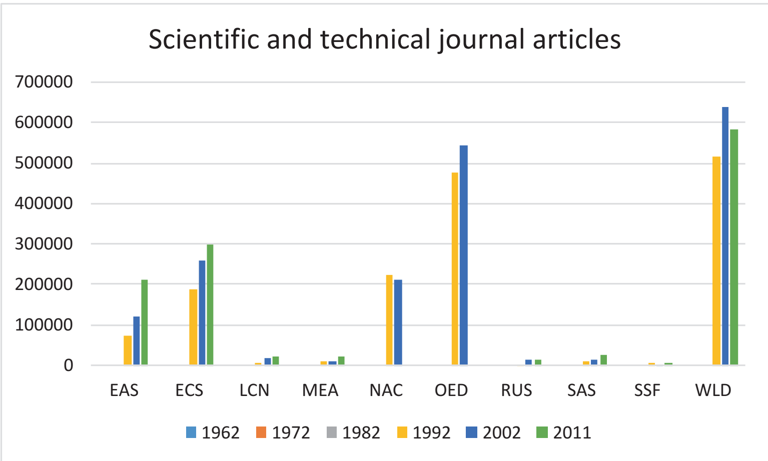

Fig. 1.23 Total number of scientific and technical journal articles published per year in different regions

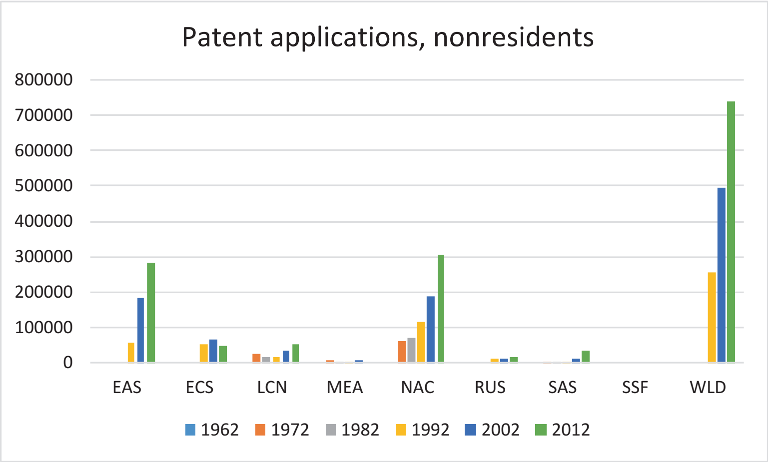

Fig. 1.24 Patent applications per year in different regions

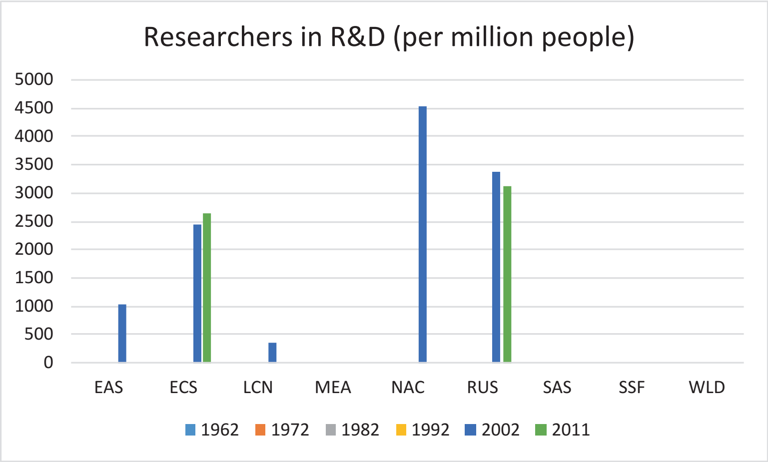

Fig. 1.25 Number of researchers per million people in different regions

research is performed in South Africa and Egypt and some other North African countries, but still not to such an extent that it is seen in the diagram. It will probably take longer before the amount becomes significant in Africa South of the Sahara, although the trend is clear.

A new tool for development is internet access. You can communicate with others by having internet. Often this is only for fun, but it is also very important for doing business, especially in countries with poor infrastructure with respect to, e.g. banks. In Africa a farmer can agree with a retailer to sell his products by internet; agreement that the retailer picks the things up at a certain place and time, and pays a certain amount of money. The payment is also made by internet directly from the buyer to the farmer without any banker in between. The farmer does not need to spend time and money to take his products to a market place, where he does not know if he can sell his goods. Instead he can spend his time on finding a buyer that will pay as much as possible.

The money he/she earns then can be used to develop his (or her) business by buying better seeds, fertilizers etc. These things can also be bought at the best price through the internet.

Other people can build PV cell stations to load the mobile phones used for communication. Through this local business is developed. A chain of different businesses develop and society can start getting tax to support common functions and infrastructure (Fig. 1.26).

It is very interesting to see how the number of internet users has increased all over the world. It started in the US and spread first to Europe and now is significant everywhere, most interestingly in Africa South of the Sahara, which has often been behind other regions in most economically important aspects. This is very promising for further development and gives the possibility to do step changes in the economic development. Instead of having to first start banks to support industrialization, we see a direct route through the internet that might also be the future in other countries. Banks may be something we talk about in the future, but do not really use!

We already mentioned the number of researchers, journal publications and patents, but there are also other items included in the total expenditures for research and development. This includes research grants given to industry or internal development work at the industries. In Fig. 1.27 figures are presented showing how much of the GDP is spent on R&D activities. We can see that North America spends approximately 2.7% and China 2.5%, while Europe approximately 1.8%. Still it should be noted that these figures are probably not directly comparable as often different authorities and companies use different methods for the calculations. Anyhow,

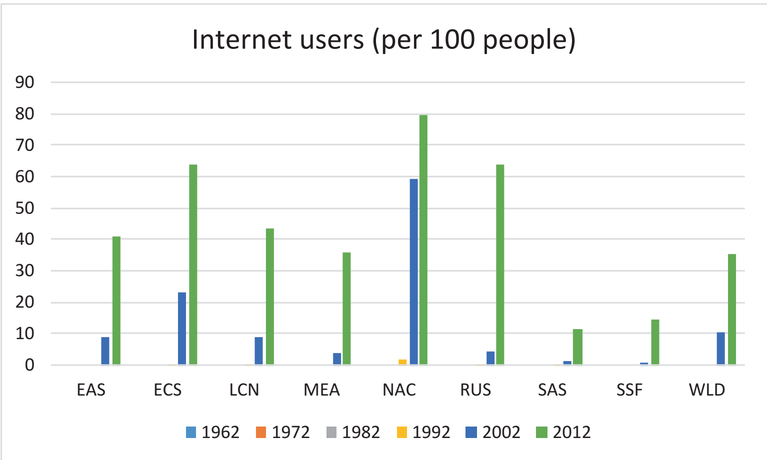

Fig. 1.26 Number of internet users per 100 people

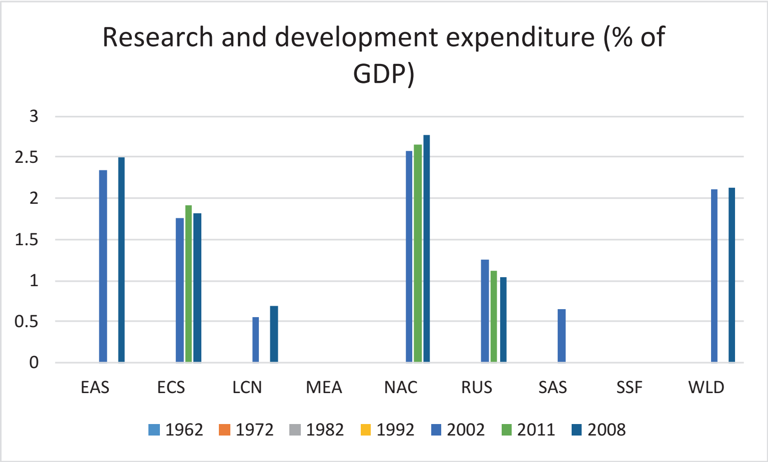

Fig. 1.27 Research and development expenditure as percent of GDP

it gives some kind of rough estimate about the order of magnitude in different countries and regions. It is clear that these three regions dominate here in the same way they dominate global business.

1.9 Railways and Other Transportation

The CO_2 emissions from transportation discussed earlier are related to both the total number of km goods and people are transported as well as the type of drive system used.

In Fig. 1.28 we see that the number of vehicles per km road is similar in East Asia, Europe, North America, Latin America and Russia, but significantly lower in South Asia and Africa. Still, as economy develops the number will increase. This is good from the perspective of good communications, but not necessarily from the perspective of environmental friendliness. Most vehicles consume large amounts of fossil fuels, as well as huge amounts of metals and fossil fuels to build the vehicles.

An alternative then is to use more collective transports like trains, which consume significantly lower amounts of energy for each person-km or ton-km for goods. In Fig. 1.29 we see how much railway transportation is used in relative values (size of the circles) in different countries and regions. We can see that the amount is very high in China and India, as well as in Europe and even Africa, but especially low in North America.

In Europe many railway lines are electrified, especially the major lines, but approximately 60% of the lines (in km) are still run on fossil fuels with diesel electric trains. The situation is similar in the UK. In many other countries the amount

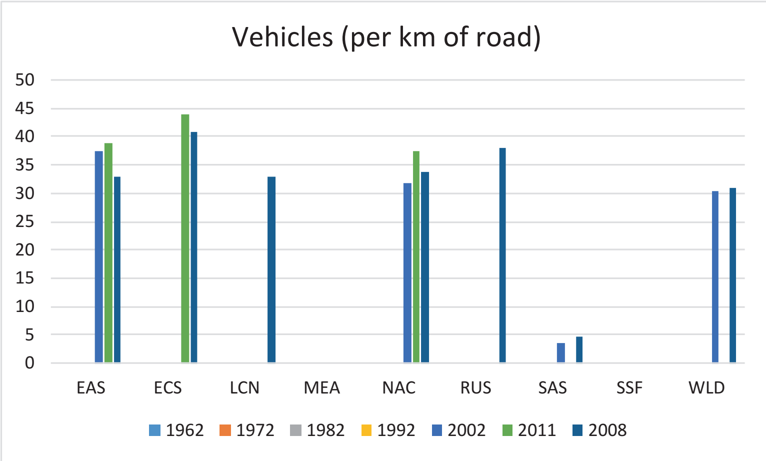

Fig. 1.28 Number of vehicles per km of road

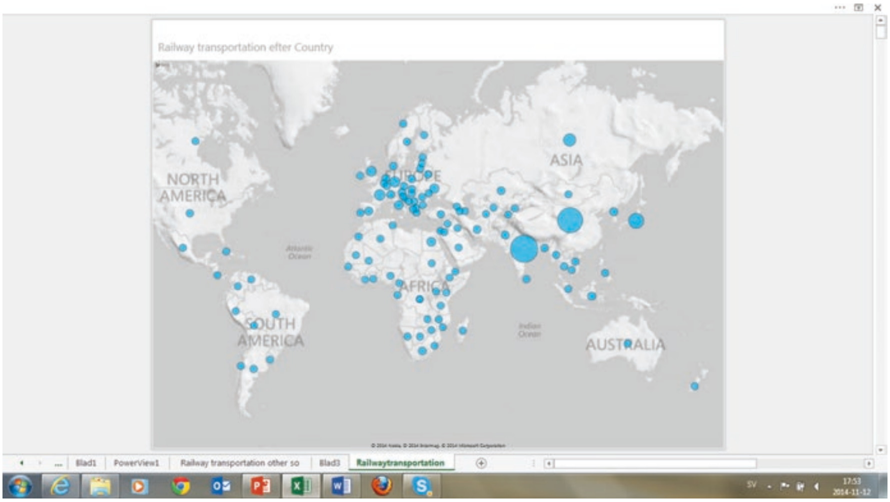

Fig. 1.29 Railway transportation in different countries. Size of circle proportionate to the absolute number

of fossil driven trains is even higher. However, we have a huge potential to electrify most train lines and in this way reduce CO_2 emissions if renewables like solar, wind, hydro and biomass thermal power plants are used to produce the power. Since the lines are fixed, the transmission and distribution to the train lines is fairly easy, and there is no need to rely on electric batteries as with single cars.

There is also a big potential to use electric batteries in trains making it possible to replace diesel electric trains with totally electric, which use batteries for one of

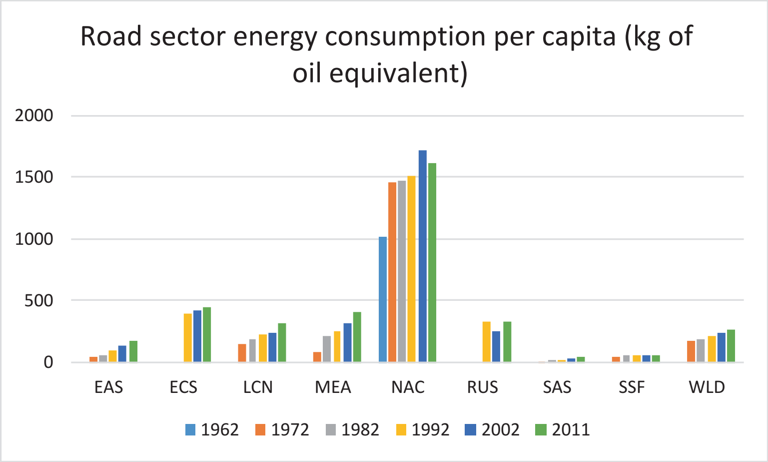

Fig. 1.30 Road sector energy consumption per capita

three drives in a train set. The batteries can then be charged at the stations or the electrolyte can be replaced if flow batteries are used. The electrolyte then can be charged with PV, wind or through the grid, and also be used as a local storage for the grid. In this way we can combine transport and stationary grid applications.

Trains are used mostly for transportation of goods in the US, and cars are primarily used for transporting people. The number of cars in developed countries is usually quite high. In Fig. 1.30 we see road transport for different regions presented as kg oil equivalents per capita. The US and North America has by far the highest, almost four times higher than in Europe, Latin America, the Middle east and North Africa, and more than 10 times higher than in the other parts of the world.

Still, we see a tremendous increase in the number of cars in most countries. This not only means an increase in use of fuel for the actual transportation, but also a very high consumption of resources like metal and plastic to manufacture the cars. This has given a push in the automotive industry and metal industry, but also created huge problems with air pollution in mega cities like Beijing, Shanghai, Mexico City, Cairo, Mumbai etc. A strong drive towards electric cars and other vehicles thus is to reduce the air pollution problems in the large cities. In Beijing, the transfer to electric buses is strongly pushed where 15 stations for battery replacements instead of fast charging were implemented in 2016, to have some 90,000 electric vehicles by 2017 (Fig. 1.31).

In Figs. 1.32 and 1.33, we see how much energy consumption in transportation is in relation to other uses of energy. In the Americas and many other countries it is approximately 20–25%, but only 5–10% in most countries. The trend of a still fast increasing percentage is alarming since in transportation it is much more costly to replace fossil fuels due to the non-stationary vehicles. Only trains can have power from the stationary grid without need for batteries. Even though electricity may be produced using renewable energy it is still very costly and resource demanding to produce the batteries. On the other hand, electric motors are much higher in

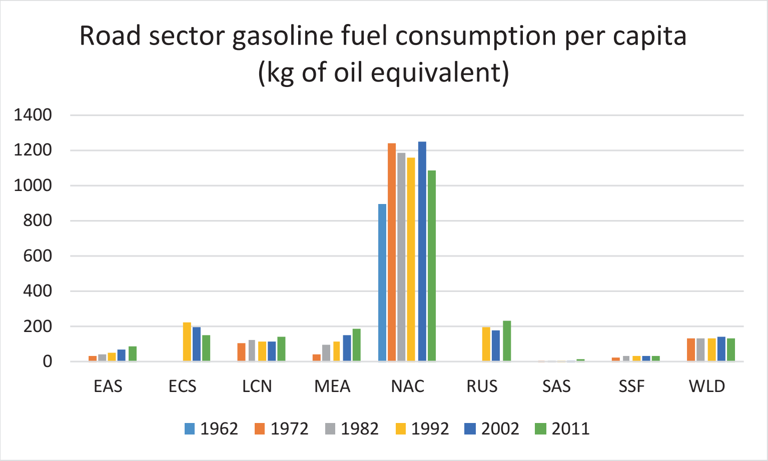

Fig. 1.31 Road sector energy consumption per capita

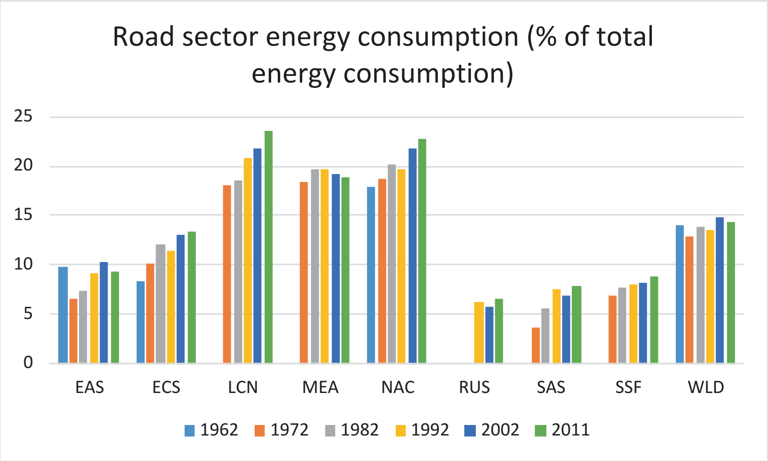

Fig. 1.32 Percentage of energy consumption in all road sectors in different regions

efficiency than diesel or petrol driven cars, which gives a lower absolute demand for energy.

We have seen a strong trend towards more diesel engines, including for cars, over the last 10–20 years because the efficiency was higher than for petrol engines. Lately, the petrol engines have achieved much higher efficiency and now the difference is small. Due to problems with particle emissions from diesel engines as well as NO_x, Toyota, the biggest car manufacturer made a decision in 2016 to stop producing diesel engines, and now focuses on hybrids with petrol + electric drive, completely electric and fuel cell electric. In the latter, primarily hydrogen is used as the fuel. The big scandal in 2015, where American authorities found out that VW cheated on their

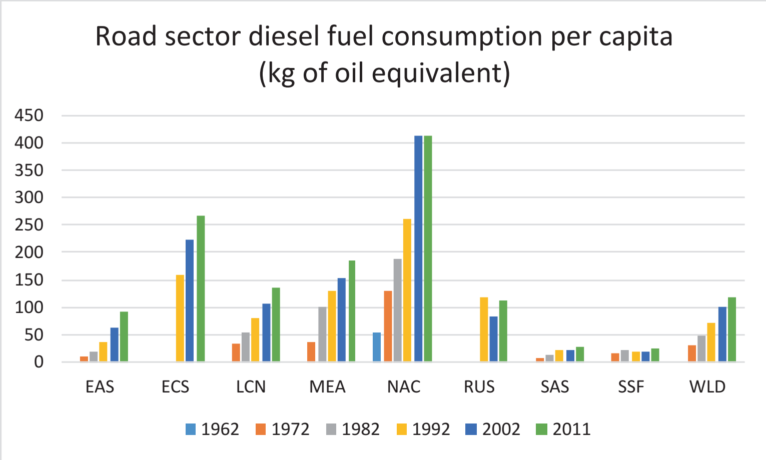

Fig. 1.33 Diesel fuel consumption per capita in road sector

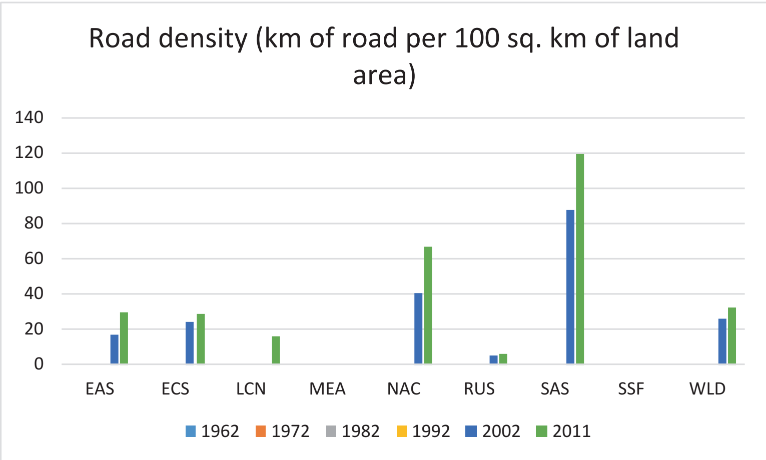

Fig. 1.34 Km of roads per sq. km land area in different regions of the world

emission technology using an electronic fix that switched operational modes during testing of NO_x emissions, will probably further reduce interest for diesel engines. What were considered as environmentally friendly vehicles suddenly became the opposite! Independent of what type of vehicle we have, roads are needed. In Fig. 1.34 we see the road density as km road per 100 sq. km of land. Here, India has the highest reflecting a highly populated country with not very many sq. meters per capita.

If we instead look at road density as a function of average income in different economic groups we get Fig. 1.35.

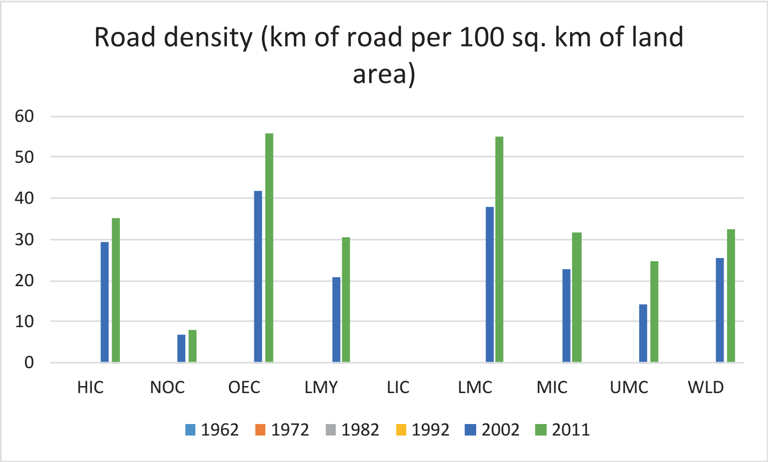

Fig. 1.35 Km of roads per sq. km land area in different economic groups of the world

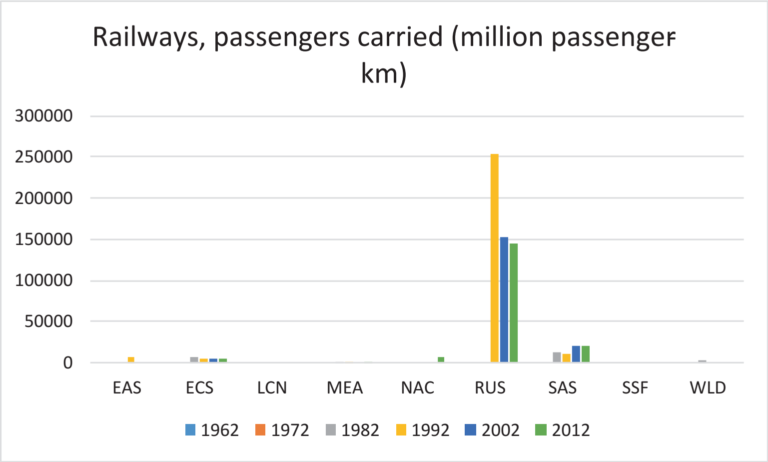

Fig. 1.36 Passengers using railway as million passenger-km

It is interesting to note that here the difference is much smaller than for the distribution between geographic regions, indicating that geography is more important than income level for the road density.

We also see that India has a very high amount of passenger-km reflecting that rail transportation is of very high importance in India (Fig. 1.36).

Definition: Passengers carried by railway are the number of passengers transported by rail times kilometers traveled. It is counted as "Railways, passengers carried (million passenger-km)".

The total global railway transport is 2900590 million passenger-km. Railways, passengers carried (million passenger-km) varies by country. India had 978508 in

2011, China 815699, Japan 244591, Russia 139842, France 88064, Germany 79228, the UK 62729, Ukraine 50569, Egypt 40837, Italy 40554, Spain 22681, Korea 21603, Pakistan 20619, Indonesia 20283 and South Africa 18865. These are the 15 highest on the ranking list out of 110. A bit astonishing are the low values for the US (9518), Canada (2886) and Brazil (1138); evidently, large railways are not used much in these three countries. The country with the lowest value in the world is New Zealand, with a value of 0 [World Bank, Transportation, Water, and Information and Communications Technologies].

For goods transport the situation is quite different for countries like the USA, with 2524585 Railways, goods transported (million ton-km). In Fig. 1.37 we see goods transport for different regions. The values in the World Bank statistics seen in the figure are a bit obscure when extracted from the huge data sheet, but the actual figures given by the World Bank in key indicators look more reliable.

In Russia the corresponding figure is 2222388, India 625723, China 2518310, Canada 352535, Brazil 267700, Kazakhstan 235846 and Germany 105894. These contribute most of the world's railway transportation for goods. It is difficult to judge the accuracy of these figures, as e.g. North America only shows half the figure of only the US! If we add these together we get 8852981 million ton-km. Thus, the agglomerated figures in the figure above are not correct except for Russia!

Figures on total km of railroads are seen in Fig. 1.38.

Concerning total km routes we can see that this is a key number that has not been followed generally, although it would be of high interest to compare. Still, we have values for Europe, central Asia, North America and Russia. It is interesting to note that the figure for North America significantly reduced from 1982 to 2002 when the last count was done. We can see that there are many km of railroad in the US although the rails are not used that much for passenger transport.

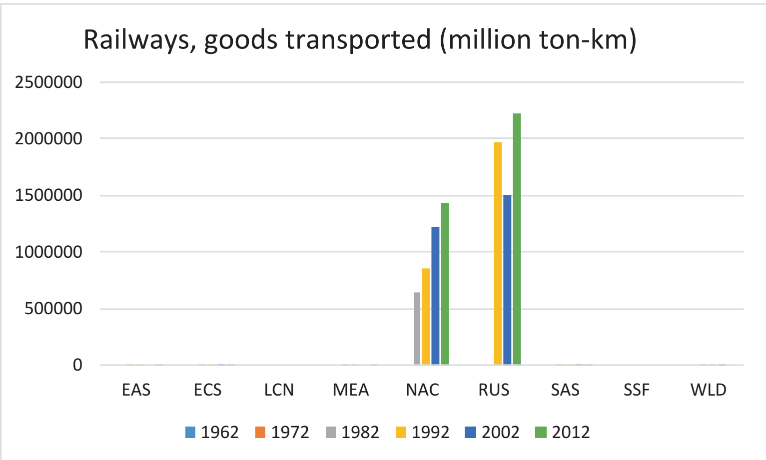

Fig. 1.37 Goods transport as million ton-km

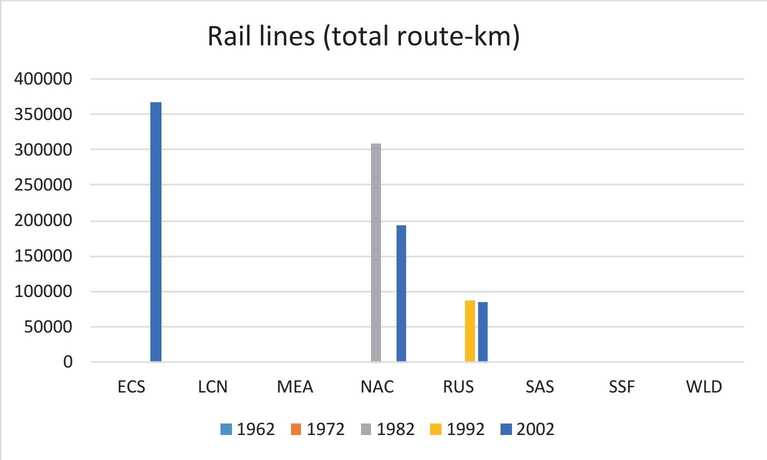

Fig. 1.38 Total km railroads in different regions

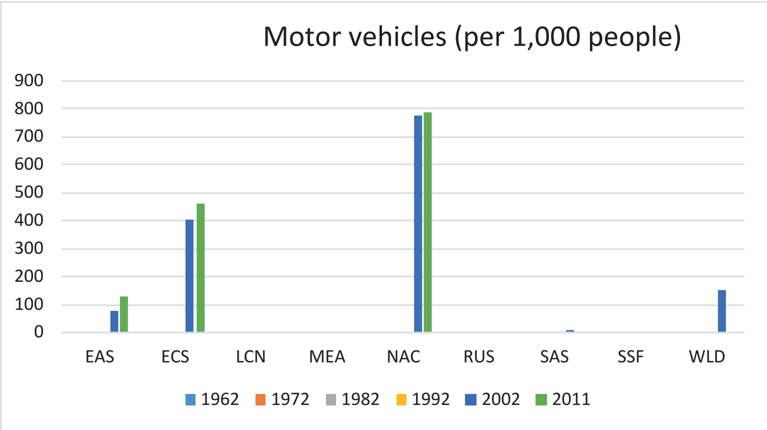

Fig. 1.39 Number of motor vehicles per 1000 people

When we look at the number of vehicles per 1000 people we see the opposite situation in Fig. 1.39. Here, we instead see that North America is “leading the league”, with twice as many vehicles as Europe and Central Asia and eight times as many as in East Asia, although East Asia doubled the number from 2001 to 2011.

The difference concerning passenger cars is slightly lower between East Asia and North America, while it is almost as high in Europe and Central Asia (Figs. 1.40, 1.41, 1.42 and 1.43). Here, we also see that South Asia is very far behind East Asia, and Africa South of the Sahara cannot even be seen in the diagram. South America is at the world average while the Middle East and North Africa are slightly lower.

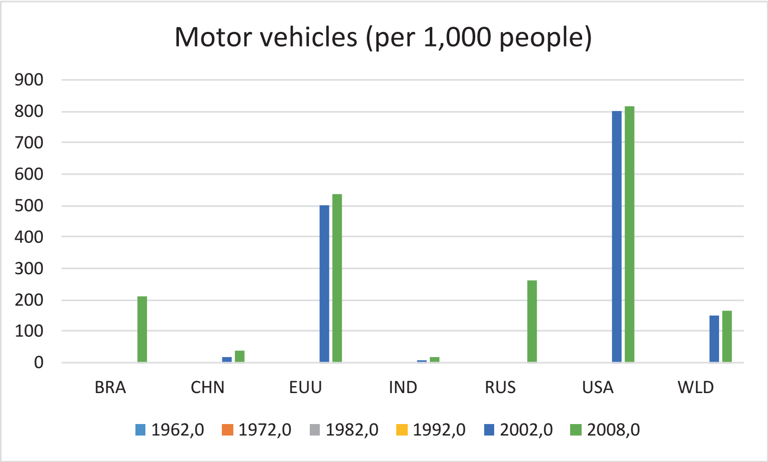

Fig. 1.40 Motor vehicles per 1000 people in selected important countries

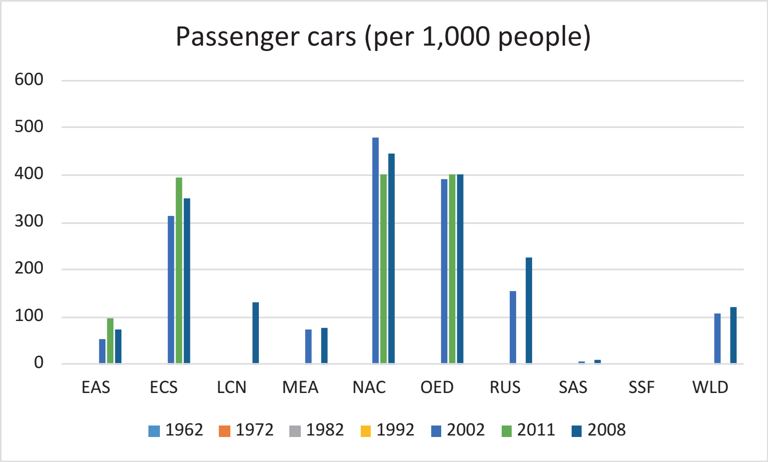

Fig. 1.41 Number of passenger cars per 1000 people in selected regions

In Fig. 1.40 we see only the EU with respective to the USA; here, the figures are the same in the US as in the whole of North America, but significantly higher in the EU compared to the EU and Central Asia. This reflects the different economic conditions in the EU compared to Central Asia generally. We also can see that Brazil and Russia have very similar numbers, while China and India can hardly be seen in the diagram.

For passenger cars we see a similar trend.

We see quite a different picture concerning air transportation. It is highest in East Asia with 50% higher ton-km compared to both Europe and Central Asia and North America. The Middle East and North Africa have half the number of these two,

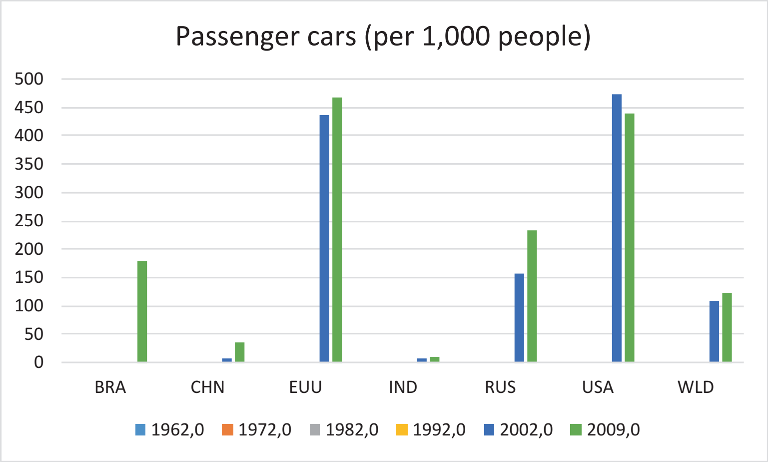

Fig. 1.42 Passenger cars for selected important countries per 1000 people

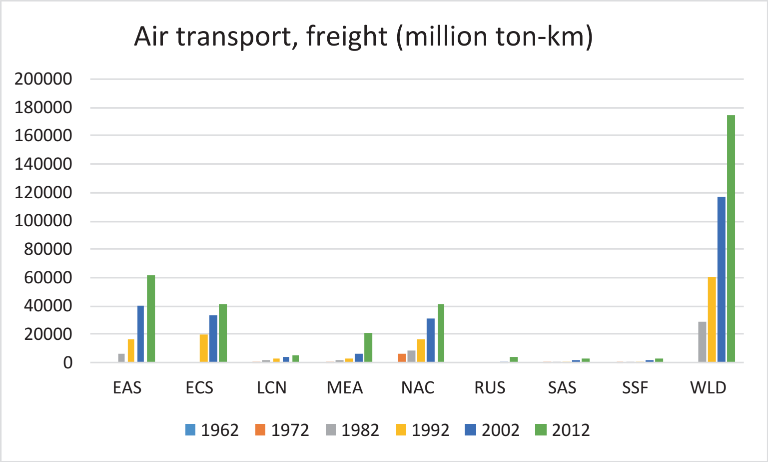

Fig. 1.43 Air transport, freight, in million ton-km in different geographic regions

which is astonishingly high, while for South Asia, South America and Africa South of the Sahara it is much lower.

Brazil is the most interesting country when considering alternative fuels, since a significant part of all fuel used for transportation is actually bio-ethanol produced from sugar cane. Even most of the energy for distillation and processing uses the bagasse from the sugar cane, which means that the bio-ethanol really has a very low impact on climate. The US also produces large amounts of ethanol mainly from corn/maize. In the US the, driving force is to subsidize farmers in the mid-west by giving a fixed amount for each litre ethanol produced from crops. There is no regulation on how it is produced, and thus cheap coal is often used for the distillation and other thermal processes. Therefore, the impact on climate becomes much higher than for Brazil. Von Blottnitz and Curran (von Blottnitz and Curran 2007) discuss bio-ethanol while Huber and Dale (2009) discuss other bio-fuels for replacement of fossil diesel and petrol. Jakobsson (2012) reviews all data on known oil reserves globally, and how much we can possibly expect to get from these. What can be seen is that there have been very few new findings of large oil reserves. Most of the new resources are from better evaluation of existing wells with reservoirs larger than originally expected. From these figures we can predict that we probably have used half of the existing oil reserves that are relatively easy to extract right now!

1.10 Sustainable Industry

An important factor for use of resources is industry, where most materials used are processed. If the processes are efficient much less material will be consumed than if large amounts are scrapped.

Product design is also important here. If we can produce a product with certain functions consuming much less material, it will have a large impact on the total material consumption. For large volume products like mobile phones, computers, TVs, cars etc. this has a tremendous effect on the total global material use. Thus, it is very important to drive technology development further all the time. If everyone shall be able to have these products, which principally everyone would like to have if they can afford it, a material crisis may occur. In some areas today, we can already see that there is a shortage of some specific materials or element, and the prediction says that some others will soon be limited, like phosphate and oil.

Due to this, it is important to also design products so that the materials can be recovered without too much effort. Unfortunately, the trend in many cases is the opposite. Instead we make compounds of different type of materials that make the recycling very costly, as the separation of the material is difficult. For some materials, impurities from other elements can cause very different material properties, like electric properties in conductors and semi-conductors. The procedure to clean these is often very energy intense if we use electrolysis. This is something for engineers to keep in mind when designing all kinds of products.

We can start worrying about what will happen to all the PV cells that are produced. What will happen to the materials after use, within some decades? Will the trace elements just be kept mixed with silica, or can they be recovered and used again? In other materials like permanent magnets used in modern wind power plants rare elements like Cobalt and Neon may be used; are these going to be recovered in a good way? Could we use other materials instead?

For solar PV cells a lot of development work is being performed to make it possible to use Iron oxides or sulfides or Copper oxides or sulfides instead of the rare elements used toady like Indium, Antimony, Arsenic and Selena. This would give a much better situation from a resource point of view.

Another aspect is scrapping. For many products scrapping is very high. You do not see it directly, as the scrapping is of different types. If we take a metal sheet we first have a variation in the thickness, and the surface is not as flat as wanted. The thickness may be different over the width as well. Thus, to get a nice sheet we cut off the edges and grind the surface to make it equal over the whole sheet. In the next step we cut out the pieces we want.

Another very important material and industry is pulp and paper. In many developing countries, paper of all kinds is needed: tissues for hygiene purposes, packaging for handling products of all kinds (Karvinen 2011 and Arve 2011), newsprint and fine paper although decreasing fast in many western countries, especially in the US (SPCI 2011). This situation is driving corporations to take a lot of new actions. Old plants are closed and new, larger ones erected. In China, 10 years ago there were some 7000 small plants. These have no recovery systems and thus pollute rivers and air. The environment improves by closing small plants, and the large, new ones have the necessary new technology to reduce emissions and more efficiently utilize the biomaterial. There are also recycling mills for packaging and newsprint paper erected in many countries, which give cheaper raw material (Thomas 2010). There may be a competition between using wood fibers as raw material for new products like dissolving pulp for textile use instead of wool (SAPPI 2011) and use in power plants (Croon 2010 and Thorp and Akhtar 2010). Lennart Holm at Perstorp (2011) believes we will soon use biomass for principally all chemicals produced from fossil fuels like oil, and Perstorp already makes all their chemicals from wood fiber source! In Asia, APP (2011) and APRIL (2011; Asp 2011) are two companies with bases in Indonesia, but strongly expanding into China. In the US companies like International paper (2011) and Weyerhaeuser (2011) also drive efficiency improvements and change into products for the future. In Scandinavia, Storaenso (Jukko Karvinen 2011) started a new nano-fiber production facility in Finland, and plans more, while newsprint paper machines are closed. SÖDRA (Krögerström 2010) rebuilt the mill in Mörrum to dissolve pulp, to meet future demand. Several other mills have done the same, which short term gives some surplus, but will probably expand long term. Later in this book we will discuss bio-refineries more, which are very important for the future. Lagus (2011) further discusses future uses of wood fibers.

1.11 Regional Development

1.11.1 Africa

Africa is a very complex continent. After years of difficult conditions, in many countries we can see very positive development over the last 10–15 years. This has happened without much notice in most media, but still gives hope for the future. I recently read two books about Africa. The first was by Richard Dowden titled “Africa. Altered states, ordinary miracles ” Portobello Books Ltd, published in

2008. In this book Richard Dowden gives a mostly quite negative picture of the continent with much corruption, a lot of wars and people killing one another. He has many memories from 40-50 years back, and describes Africa from these experiences. It is then quite interesting to read the other book "The New Africa" by Erika Bjerström, 2013, Weylers. She is a correspondent for Swedish Television and travels around reporting from all over the continent. One chapter gives hope, while another despair!

Erika Bjerström first refers to Steven Radelets book "Emerging Africa", Center for Global Development, 2011. Steven has divided Africa into four categories. There are 48 African countries. Sixteen of these are called "Lion economies" as there was steady growth from 1996–2008 at more than 3.2% per year, and democracy also developed. These countries are Botswana, Burkina Faso, Cape Verde, Ethiopia, Ghana, Lesotho, Mali, Mauritius, Mozambique, Namibia, Rwanda, Sao Tome, Seychelles islands, South Africa, Tanzania and Uganda.

The most impressive growth has been in Botswana with 6.3% per year over almost 40 years. The country became free in 1968, receives a lot of income from diamond mines, and has been democratic and peaceful during this period.

Another seven countries are Zambia, Liberia, Benin, Malawi, Senegal, Sierra Leone and Kenya. These countries also have close to 3.2% growth per year. The remaining 16 countries are Congo-Kinshasa, Central African Republic, Eritrea, Niger, Somalia, Ivory Coast, the Comoros, Djibouti, Gambia, Madagascar, Togo, Swaziland, Zimbabwe, Guinea, Guinea-Bissau and Burundi. These countries have had problems with violence, non-democratic issues and great hardship for the population.

The fourth group is the oil-producing countries. These are Angola, Chad, Cameroun, Congo-Brazzaville, Equatorial-Guinea, Gabon, Mauretania, Sudan and Nigeria. In these countries the national income is high and increasing, but due to corruption and "bribing the population" with benefits paid by the oil, the development of society and non-oil industries is much slower than in the "Lion-countries".

In the "Lion-countries" income per capita has increased by 50% since the 1990s while it has been almost the same in the "problem countries".

The African countries did not suffer from the economic crisis starting in 2008 and instead agreements were made to reduce the debts for most African countries. Over the last 15 years plans were made between World Bank, IMF and 42 African countries. Thus, many African countries have taken control over their economies, which we do not hear much about for some reason?!

The development of democracy has also taken big steps. Twenty five of 53 countries are considered democratic while another 22 have acceptable elections as well. The number of coup d'état reduced by half since the 1990s. Where attempts are made, many are stopped quickly like in Burkina Faso in September 2015. After the 2015 elections in Nigeria the replacement of the president proceeded without armed conflicts, which is a very promising sign that democracy can also be achieved in big oil rich countries. This hopefully will have a good influence on other countries.

China and other countries like India, Brazil, the US and Turkey are investing in different African countries, but most trading is with EU countries.

Sten Rylander (2012, 2014, 2016), the Swedish ambassador to Zimbabwe, Botswana, Namibia, Angola, Tanzania, Burkina Faso, Malawi, Lesotho, Mozambique and Madagascar over 40 years, has written several very interesting books about Africa from an insider perspective. Sweden supported ANC strongly during the apartheid time in the fight for democracy. Sten Rylander and his wife personally supported both ANC and other freedom groups in the area until freedom. He gives very good overviews over both historical development and the situation today, as he knows most of the leaders personally. Kuchler (2010) is discussing how biomass use should be promoted in developing countries and in World bank development indicators (2013) we can see that biomass is a very important energy resource already in many developing countries. Long term this will be more valuable than the fossil fuel resources now beeing promoted in several African economies strongly. This is also discussed in Dahlquist (2013b).

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Chapter 2
The Challenges of Measuring Sustainability Performance

Stefan Hellstrand

When dealing with systems where sustainability is an issue, you are dealing with systems where life, i.e. bios, matters. Without life no subject would be present caring about whether something is sustainable or not.

For systems where life is a defining characteristic the following typically occur

- Thresholds
- Irreversibilities
- Mutual dependencies between
  - Systems such as ecological, economic and social ones, and
  - System levels from subcellular physiological processes, such as photosynthesis and the physiological processes of cows and the rumen microbes in interaction to sustainable global food and bioenergy supply
- The phenomenon called resilience.

Altogether, this contributes to the complexity of systems where life, bios, is a defining system characteristic.

Figure 2.1 illustrates this.

The level of system complexity is further enhanced when including humans, due to the values, preferences and opinions of over 7 billion individuals in a spectrum of networks and organisations.

From a system ecological perspective, the human economy is a subsystem within ecological systems. Ecological systems deliver ecological goods and services, such as energy resources, material resources as well as the capacity of ecosystems to take care of wastes and in solar driven processes upgrade them to new resources.

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Springer International Publishing AG 2017
E. Dahlquist, S. Hellstrand (eds.), *Natural Resources Available Today and in the Future*, DOI 10.1007/978-3-319-54263-8_2

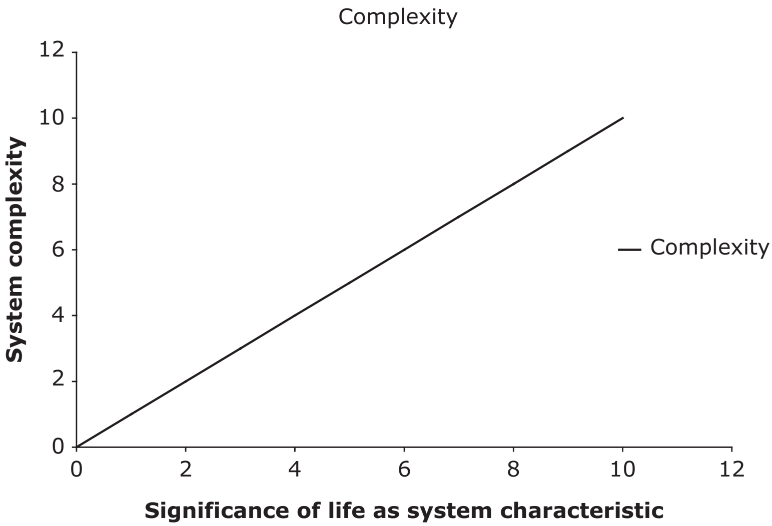

Fig. 2.1 Principle relation between the complexity of systems and the significance of life as system characteristic

Figure 2.2 presents this system using symbols and expressions common in systems ecology.

There are three independent energy sources to the global economy; solar energy, tides and energy from nuclear processes within the earth. Solar energy works through solar radiation, wind and rains. Hydro-power is a transformation of solar energy. Fossil fuels are the products of photosynthesis a long time ago. Bioenergy represents products of photosynthesis in near-time.

Figure 2.2 presents a strongly simplified version of reality. Real world systems are characterised by high level of feed-back mechanisms from the physiological processes within an organism to global carbon cycles. There are also feed-back loops between subcellular physiological processes and the global carbon cycle.

Within the human economy there are related biophysical and monetary fluxes. Labour, capital and natural resources go in one direction, their payments in the opposite one.

There is a pedagogic problem with Fig. 2.2. It presents a scientific language used to describe integrated ecological-economic systems that is unfamiliar to most people.

Figure 2.3 shows the same system using the language of economics.

The model contains three compartments. Ecosystems including natural resources (NR) constitute *Compartment I*. Sun, tide and processes providing heat in the depths of the Earth are independent power sources driving processes in economic and ecological systems. According to the first thermodynamic law the amount of energy

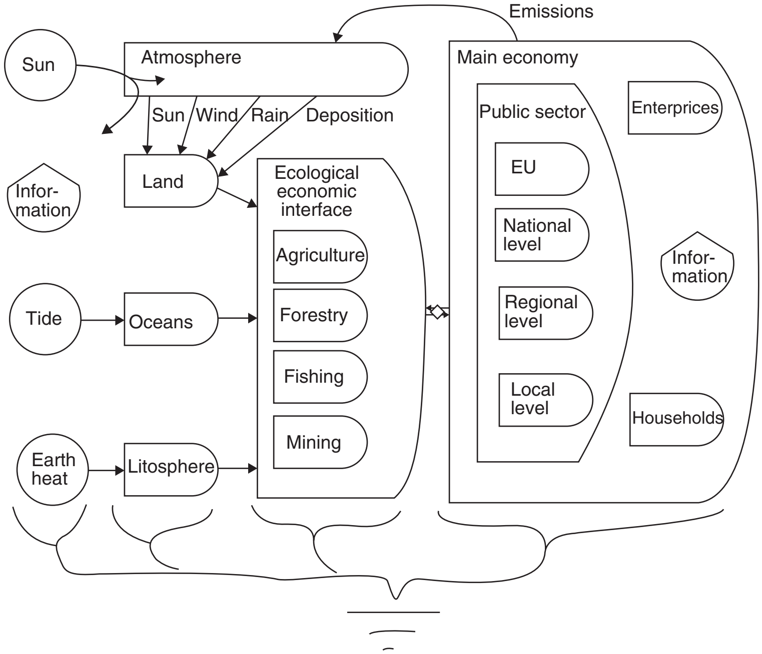

Fig. 2.2 A model of the global ecological economic system from the perspective of systems ecology based on the contributions by Odum (1988, 1996)

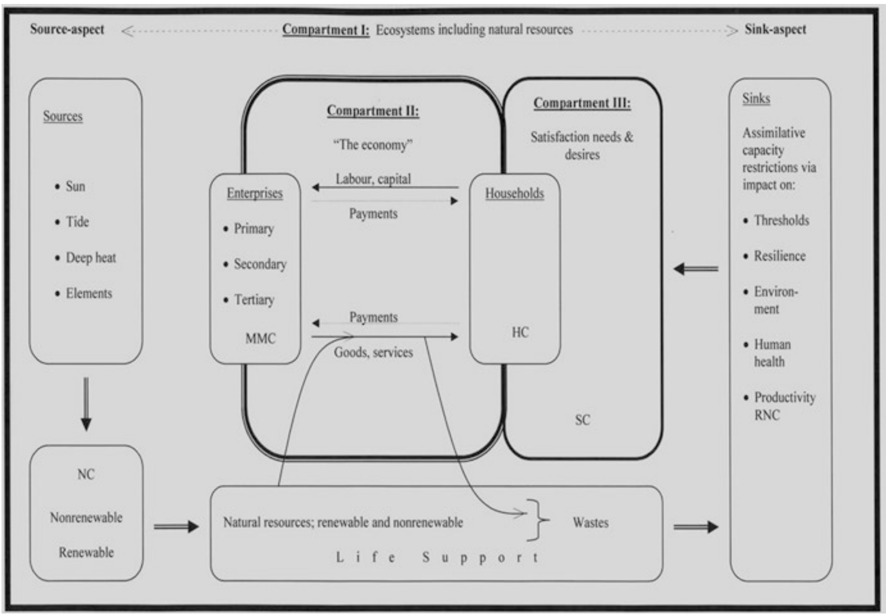

Fig. 2.3 A conceptual model of the economy in its ecological and social context (From Hellstrand et al. 2009). Abbreviations used in Figure. *HC* human capital, *MMC* man-made capital, *NC* natural capital, *NNR* non-renewable natural resources, *NR* natural resources, *RNC* renewable natural capital, *RNR* renewable natural resources, *SC* social capital

is constant while according to the second the quality of energy is degraded in real world processes (Pimentel and Pimentel 2008). The amounts of elements are assumed to be constant. Although this is not correct with regard to nuclear processes, it is an appropriate assumption for the purpose of this paper. In geobiophysical processes driven by independent power sources, elements are rearranged into stores of natural capital (NC). NC provides life-support, that is, the physiological necessities for life (Odum 1989). The economy consumes renewable and non-renewable natural resources (RNR and NNR, respectively), appropriated from the stock of NC. The availability of natural resources (NR) provides source restrictions to the economy. This is the source-aspect of ecological sustainability.

Ecological sustainability also includes a sink-aspect. The sink-aspect refers to the capacity of ecosystems to assimilate wastes from the economy without such negative environmental impact that the life-support capacity is threatened. Land-use may also affect the life-support capacity, and thus may be constrained by ecological sink-restrictions. The impact of the economy on thresholds, resilience, environment, human health and the productivity of renewable natural capital (RNC) is crucial in the understanding of how Nature through ecological sink-restrictions through the pressure Man puts on Nature, affects future human wellbeing.

In *Compartment II*, energy and other resources are transformed to goods and services measured in terms of GDP in processes steered by man-made and human capital (MMC and HC, respectively). HC refers to the capacity of the individual to contribute to production in Compartment II. It is a measure of the productivity of the individual. The primary sectors[a] act as a bridge between the first and second compartments, making NR available to the rest of the economy.

In *Compartment III* ecological goods and services produced in Compartment I as well as goods and services produced in Compartment II are consumed, satisfying human needs and desires. Social capital (SC) is related to the degree of social sustainability and is connected to aspects such as democracy, legitimacy of authorities and distribution of resources. At the interface between Compartments II and III, consumer prices and production values are established. Compartment II, including the interfaces to Compartments I and III respectively, is the primary focus in economics. It can be called the GDP economy. Prices are important information carriers and the basis for production and consumption decisions by market actors. Consumer surpluses describe the social value of the goods and services consumed and invested. GDP is an estimate of production, not welfare.

Compartment I defines ecological restrictions to society, Compartment II provides the means, while Compartment III contains the objective; human wellbeing.

The sustainability map in Fig. 2.3 is inspired by the way the ecological economic system was presented in ecological economics in the early 1990s. Important contributions were made by Herman Daly (Daly 1990; Daly and Cobb 1989) and Robert Costanza around 1990 (Costanza 1994; Costanza and Perrings 1990), as well as Hall et al. (1986). From this perspective, the path towards sustainability is described as

- A substitution of non-renewable natural resources with renewable ones
- Efficiency in the use of non-renewable natural resources as well as renewable natural resources

- A restriction of emissions and discharges from the economy to be within their assimilative capacity
- A restriction on land-use changes so that the life-support capacity of the landscape is not harmed too much.

OECD (2001) follows close to the perspective of the economic system as a part of the ecological system laid out by these authors. The challenges to handle are presented in the beginning of this chapter.

The brothers Eugene and Howard Odum are pioneers within systems ecology. Figure 2.2 represents their perspective of the economic system in its biogeochemical context. Within ecological economics, their description was translated into the language of economics. However, Figs. 2.2 and 2.3 basically describe the same system with the same basic subsystems and relations.

The model in Fig. 2.3 is a basis for later approaches from an economic perspective to understand what a sustainable economy is, such as

- OECD (2001) and their report *Policies to enhance sustainable development*
- Beyond GDP[1]
- The Economics of Ecosystems and Biodiversity (TEEB 2010).[2]

The perspective in Fig. 2.2 formed the basis for the thorough exploration of the state of the ecosystems of the earth and their delivery of ecosystems services supporting human wellbeing, initiated by the Secretary General of the UN at that time Kofi Annan, under the name Millennium Ecosystem Assessment (MEA[3]). E.P. Odum describes the life-support capacity of ecosystems as their basic capacity to provide the physiological necessities for life on earth. This includes clean air, clean water, food, forestry resources and natural resources in general. MEA follows this structure. Ecosystems, according to this perspective, support human wellbeing in three paths.

1. Natural resources can be upgraded to economic goods and services
2. The capacity to take care of emissions from society and often in solar energy driven processes, such as photosynthesis, upgrade them to new resources which can be utilised in a new circular loop in the ecological–economic production system
3. A landscape which is the product of ecosystems interacting with their geological contexts over millions of years, in which humans feel good.

If 2 represents a regeneration of wastes from society to resources, 3 refers to the regeneration of human minds and souls.

[1] See http://ec.europa.eu/environment/beyond_gdp/index_en.html, accessed 2016-08-07.

[2] TEEB 2010. Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB, http://doc.teebweb.org/wp-content/uploads/Study%20and%20Reports/Reports/Synthesis%20report/TEEB%20Synthesis%20Report%202010.pdf, accessed 2016-08-07.

[3] http://www.millenniumassessment.org/en/About.html, accessed 2016-08-07.

Regarding "circular loops" in ecological–economic systems this is a half truth. Elements and material can be recycled (almost) in infinity. Energy resources cannot. While the amount of energy is constant, the quality of energy in all processes we know of relevance for the human economy and society is decreased. Thus, the circular loop of material in the economy, in ecological systems and in integrated ecological–economic systems is driven by a linear flow of energy with quality that is degraded. This is important to know, as this puts limits on the physical volume of the human economy that can be sustained.

Taking the life-support systems of ecosystems into account as well as the economic and social parts of the human economy, we arrive at ecological, economic and social restrictions to the volume and character of what can be called a sustainable economy. This is narrower than the physically restricted maximal volume of the human economy.

The ecosystem-perspective of the economy in its ecological context, with the life-supporting systems in a central position, is quite similar to how these systems were described in classic economic theory during the eighteenth and nineteenth century, in which three production factors were identified; land, labour and capital. Labour refers to human capital in Fig. 2.3; capital to man-made capital; and land to natural capital. This way of presenting the economy, as a part of the natural system, was common in agricultural economics during the first half of the twentieth century. For centuries and millennia, society has constantly faced the challenge of managing agricultural and forestry systems in such a way that the harvest in the short term was high enough, while maintaining and enhancing the long-term productivity. During this course, analytical and management tools evolved with the basic capacity to handle the system characteristics presented in the beginning of this chapter.

Taking the analytical and management tools developed during centuries of experiences and scientific evolvement in agriculture and forestry together with the recent contributions in systems ecology briefly presented, results in a complementary description of what a sustainable society and economy is.

In a sustainable society and economy the long-term production of ecological goods and services, i.e. sometimes called ecosystem services, is greater than the consumption from the economy and society. The sustainable supply is greater than the demand. This focuses on the ecological part of sustainability. It is then the task of the economy and society to make use of the sustainable level of ecosystem services delivered, in a way that supports a good economic and social development within the ecosystems carrying capacity limits. This is not in conflict with common principles of sustainable development discussed above in relation to Fig. 2.3. It is another way to describe the same thing.

In Chap. 4, the supply and demand perspective of ecosystem services is applied on the issue of biological resources available for the economy from agriculture and forestry.

OECD (2001) identified an implementation gap and a knowledge gap as major obstacles for a sustainable development. From their perspective, the knowledge about what a sustainable development is and how to achieve it is quite good. However, the implementation of policies for sustainable development is poor and uneven.

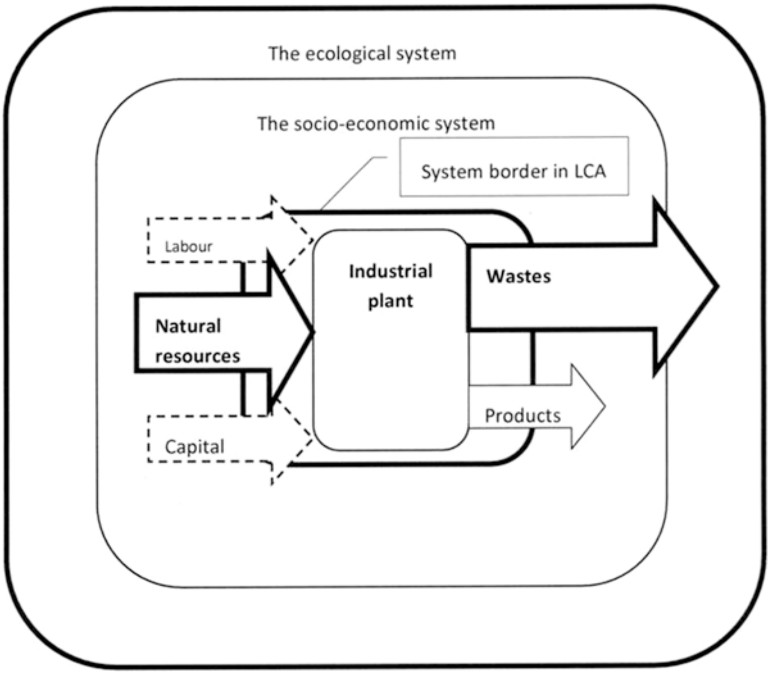

Fig. 2.4 LCA and the sustainability context

Hellstrand (2015) found that this situation could be specified. On a general level with a macroeconomic and what you can call a macro-ecological perspective, the challenge is quite easily expressed:

- Get the prices right so that they reflect positive and negative environmental and human health effects,
- Remove subsidies that support unsustainable choices,
- Apply policies that are neutral between sectors.

The problems occur when it comes to the everyday choices that all together determine whether the path towards the future is sustainable or not: On the operative level, choices aimed at sustainable development often miss the target as they rely on the rationality of models, approaches and methods that do not represent the knowledge frontier in those disciplines that represent the competence of excellence regarding the systems and issues that are at the focal point when sustainability is an issue.

Figure 2.4 illustrates the situation. It shows the gap between the characteristics of real systems according to the best available knowledge and the characteristics of the models of real systems used in different analyses aimed at supporting a sustainable development. Commonly, they are based on the logics of Life-Cycle Assessment (LCA) as defined within SÍSO 14040 and ISO 14044.

LCA is a methodology that was developed in the engineering sciences; thus, its scope is limited and excludes vital features of systems where life is a key system characteristic, as shown in Fig. 2.4.

The engineering-based conceptual model of the production system is the industrial plant. The importance of labour and capital (using their traditional meanings) is ignored. Furthermore, the model suggests that there are no natural resource costs behind humans, labour and capital. The focus is on influxes of natural resources, and effluxes in the form of wastes. Products and product quality in relation to their usefulness in the socio-economic system are typically treated with substantially less accuracy.

With its background in engineering sciences, LCA has its strengths in analysis of the technical aspects of industrial production processes (see Baumann and Tillman 2004). Inputs of natural resources into the production system and emissions out of the production system, where the industrial plant is the mental model used, are handled easily. Problems arise because engineering sciences do not provide expert knowledge regarding the ecological, economic and social process restrictions that define the level of sustainability in specific production situations. To overcome this limitation in the understanding of the total sustainability, different assumptions are made, providing analytical shortcuts. For example, it is commonly assumed that there are no time and space dependent variations whatsoever in conditions in ecological systems. Furthermore, ecological carrying capacity limits are not considered. With these assumptions, the concept of ecological sustainability becomes irrelevant as there is no longer any ecological process restriction that can be affected, and thus no ecological carrying capacity limit that can be trespassed. Such assumptions devalue the results obtained, given the sustainability context. This illustrates the scientific problems of extrapolation, here on the methodological level. Methods that have proved useful within the boundaries of engineering sciences are applied outside these boundaries, generating results that carry a high risk of being inaccurate.

There are similar problems within

- The EU-directive concerning Integrated Pollution Prevention and Control and its Best Available Technology-principle,
- The Integrated Product Policy of the EU,
- The Swedish system of Environmental Accounts,

to mention three examples. The basic problems are that the environment, the ecological system, is not located within the system borders, and that the modus operandi is the scientific language of physical sciences, while it is the understanding of the features of life, of bios, that is crucial.

Hellstrand (2015) presents a tool-box for sustainable development that substantially diminishes the implementation gap. The individual tools are derived from the fields of systems ecology, economic theory, theories of complex systems and agricultural sciences.

The individual tools are

1. A conceptual model of the economic system in its ecological and social contexts, in which natural capital, man-made capital, human capital and social capital are considered, see Paper I and II, and Fig. 1.
2. Biophysically Anchored Production Functions (BAPF), where production value in the economic production process are expressed as a function of inputs of natural capital, man-made capital, human capital and the environmental impact of the production process through impact on the life-support capacity. Goods and services measured in the adjusted GDP-terms suggested are means to support the maintenance of social capital, see Paper II.
3. A contribution within participatory multi-criteria, multi-level analysis for evaluation of how a specified subsystem contributes to a hierarchy of sustainability objectives in the ecological, economic and social dimensions from low to high system levels considering typical features of complex systems such as thresholds, resilience, irreversibilities, mutual dependencies between systems and system levels (Paper III).
4. System of ecological economic accounts (EEA) obtained when specifying BAPF in time and space, where capital stocks and their changes can be focused, or the flux of economic and ecological goods and services. EEA can be used to measure the performance of any system in ecological, economic and social terms and in relation to affected systems sustainability limits, if sufficient knowledge about them is available. Tables 3 and 4 present results from evaluation by means of EEA, where it is shown how the EEA measure contributions to a majority of the 16 national environmental quality objectives in Sweden decided by the Parliament, as well as to Millennium Development Objectives from the UN. Table 7 gives outcomes on a local community, regional and national level. Hellstrand (2003a, b, 2007) used EEA to measure sustainability performance on a regional level. Hellstrand and Yan (2010) present an evaluation of whether China is an option when Sweden and the EU reduce their contribution to climate change.
5. A simulation model of animal production systems with supporting crop production where EEA for specified agricultural production subsystems are developed with included biological-economic production functions based on Hellstrand (1988, 1989). The simulation model is a development of common tools within agricultural sciences used to optimise the use of available resources of land, labour and capital. The simulation model can be used to generate data for further analysis of sustainability performance of animal production systems based on a genuine professional understanding of animal production systems, and of how balanced agricultural production systems shall be constructed where in- and effluxes in biophysical and monetary terms between systems are constant. It is also an example of and suggestion for how on a societal level to find solutions supporting a sustainable development through the combination of different stocks of capital mentioned in 1. Hellstrand (2009) elaborates on this possibility in connection with a job concerning physical planning for sustainable attractiveness in Gothenburg on behalf of Göteborg Stad. The task was to develop new methods to measure values from agriculture in a landscape dominated by urban

and industrial elements utilising the concept of ecosystem services, and then apply them. In this context EEA was used as a means for urban planning for sustainability.

By the tools 1-5 a map of the sustainability landscape in a given situation and within a given context can be generated that reasonably guides a tour towards sustainable development, considering the complexity in systems where life is a defining system characteristic, see Fig. 2.1.

A relevant map of the sustainability landscape is essential, but not enough. A compass is needed as well to assure that the sum of actions of households, enterprises and government bodies result in an overall orientation of the societal development that is sustainable.

Ecosystems deliver ecosystem services. As around 75% of terrestrial land in Sweden is classed as agricultural land or forests, most of the total production of ecosystem services originates from agriculture and forestry. Globally, the corresponding value is 70%. A sustainable situation is at hand when the total consumption of ecosystems services is within the sustainable production level. One major incentive towards achieving this is to adjust the prices of goods and services so that they reflect the value of positive and negative ecosystems and human health impacts (OECD 2001). FAO (2006), Millennium Ecosystem Assessment (MEA 2005) and TEEB[4] make similar proposals.

FAO (2006) named their proposal Polluter Pays, Provider Gets, another common expression is systems for Payments of Environmental/Ecological Services, i.e. PES. Such systems are discussed in EU,[5] UNEP as a follow up of the work of Millennium Ecosystem Assessment,[6] IUCN[7] and TEEB.[8] It harmonises well with OECD (2001), and their stress on the importance of getting prices right, reflecting positive and negative ecosystems as well as human health impacts.

Hellstrand (1998) suggested a solution based on the Precautionary Polluter Pays Principle (the 3P principle) (Costanza and Perrings 1990; Costanza 1994). The 3P principle integrated the precautionary and the polluter pays principle into a market based insurance solution. The 3P principle made it rational for enterprises to reduce (the risk of) human and ecosystem health damages caused by production. It also provided incentives where enterprises benefitted from actions that reduced the uncertainty regarding possible negative external impacts of production. In the 3P principle, enterprises have the full responsibility for possible future costs of their activities.

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[4] http://www.teebweb.org/wp-content/uploads/Study%20and%20Reports/Reports/Synthesis%20report/TEEB%20Synthesis%20Report%202010.pdf, accessed 2014-02-18.

[5] http://ec.europa.eu/environment/integration/research/newsalert/pdf/30si_en.pdf, accessed 2016-06-25.

[6] http://www.unep.org/pdf/PaymentsForEcosystemServices_en.pdf, accessed 2016-06-25.

[7] http://www.unep.org/pdf/PaymentsForEcosystemServices_en.pdf, accessed 2016-06-25.

[8] http://www.teebweb.org/wp-content/uploads/Study%20and%20Reports/Reports/Synthesis%20report/TEEB%20Synthesis%20Report%202010.pdf, accessed 2014-02-18.

With contrafactual reasoning, if the 3P principle had been in place, much of current agriculture would look different. For example, three of the most severe environmental and human health catastrophes we have experienced globally are related to the production of biocides, i.e. chemicals to control parasites, insects, weeds and fungi in modern agriculture;

- Seveso in northern Italy in 1976[9]
- The Bhopal disaster in India in 1984
- The Sandoz chemical spill in Switzerland in 1986.

If the 3P principle had been in place, the insurance costs for the companies assuring the capacity to fully cover the external costs that these events eventually caused, would have been so high, that they would not have been competitive.

In a broader perspective, this would have influenced the shape of modern agriculture, as practices causing poor human health and environmental costs would have to bear their full external costs.

However, one piece of the puzzle was still missing. The 3P principle did not link the consumption of environmental space to its production, i.e. it did not link consumption of ecosystem services to production. The 4P principle (the Precautionary Polluter Pays the Preventer/the Polluted Principle) however does this, within production levels set by affected ecosystems carrying capacity limits (Hellstrand 1998). The potential contribution of the 4P principle was discussed in relation to aspects such as: cadmium fluxes in the food system with its impacts on human health; the depression of photosynthesis, and thus production in forestry and agriculture as a result of ozone close to the ground due to emissions from society; carbon sinks in forestry as well as production permits to the forestry industry based on the so-called best available technology principle.

The 4P principle stresses the importance of not only utilising environmental fees and taxes but also reward systems when actors take measures to improve the environment and the production of ecosystem services.[10] In theory, with this kind of principle an insurance solution is enforced where environmental as well as human health risks of production systems are internalised in the price. Actors that harm the environment and/or human health are forced to pay those that bear the costs. Finally, in this system actors that produce ecosystem services that enhance the sustainability basis of society are paid for this production. In fact, the 4P principle provides a frame where for example, trading systems for emissions are anchored in the carrying capacity limits of affected ecosystems. By doing so, the market mechanism is used to enhance social and economic development in affected systems within ecological and human health limits. Solutions that provide low satisfaction of human needs per unit emissions will then be outcompeted while solutions that provide high

[9] Afterwards an EU-directive was named the Seveo-directive, with the aim to minimise risks for and effects of future accidents in chemical industries, see http://ec.europa.eu/environment/seveso/, accessed 2016-06-25.

[10] The issue of externalities and how to price them has been discussed for a long time within economics.

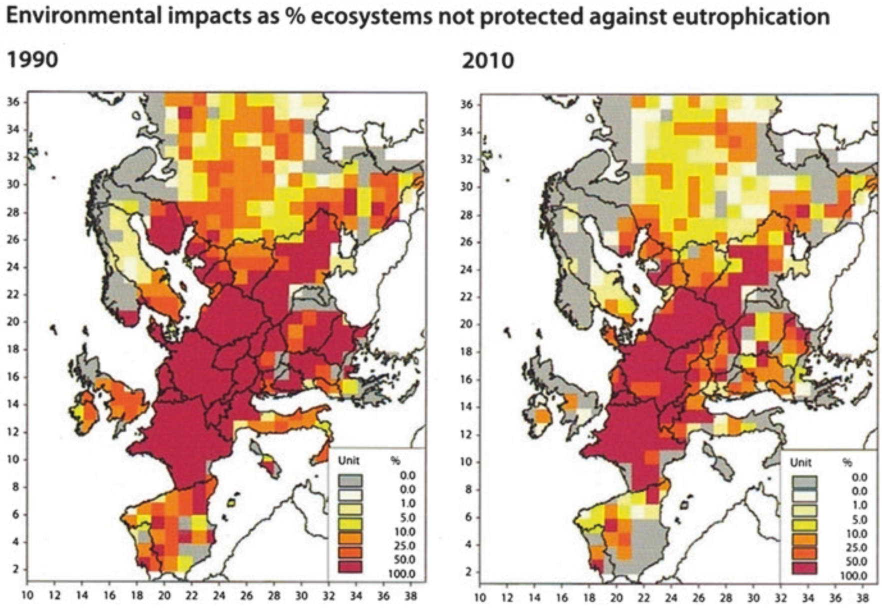

Fig. 2.5 The exceedance of critical loads for eutrophication around Europe for the base year 1990 and target year 2010 of the Gothenburg Protocol (From Pleijel 2007)

satisfaction of human needs per unit emission are favoured. At the same time, this system suggests how the total amount of emissions can be captured within the carrying capacity of affected ecosystems. It provides incentives where managers of ecosystems are encouraged to improve the production of ecosystem services; and it provides incentives favouring technological development and innovation favouring social and economic development within sustainability limits of affected ecosystems.[11]

The Swedish ecological-economic system combines industrial sectors with high resource and emission efficiency as well as ecosystems/recipients with higher remaining assimilative capacity compared to most other developed nations. The latter aspect is mainly a function of the low concentration of humans per ha of biologically productive ecosystem. The share of land area where deposition of nitrogen exceeds critical thresholds is substantially lower in Sweden compared to most EU countries (Fig. 2.5).

Figure 2.5 shows a huge variation in the degree to which critical loads, i.e. assimilative capacity limits, are trespassed in Europe. In the most densely populated

[11] This concept has been treated at a conference and a workshop at the Swedish Royal Academy of Forestry and Agriculture. The exercises are documented in separate reports, see *Jakten på den gröna marknadskraften*, in separate issues of KSLAs Journal. The first report is also available in English, *The Search for green market forces*. Links to these reports are http://www.ksla.se/publikationer/kslat/kslat-1-2006/; http://www.ksla.se/publikationer/kslat/kslat-6-2008/; http://www.ksla.se/publikationer/kslat/kslat-1-2006-eng/, all accessed 2013-01-03.

areas, which also have the highest economic activity per area unit, the critical load is trespassed for 100% of the area of ecosystems.

Emissions to air also have human health impacts. They were estimated to cause around 400,000 deaths in the year 2000 in the EU. The annual cost to society of this level of health impacts has been estimated at 270 to 880 billion € (EU-Commission 2005).

The spatial variation in ecosystem impacts through eutrophication due to air emissions (Fig. 2.5) is similar to the spatial variation in the decrease of expected life span due to air emissions of particles (Fig. 2.6). Thus, in the most densely populated areas with the highest economic activity, the expected lifespan is expected to be

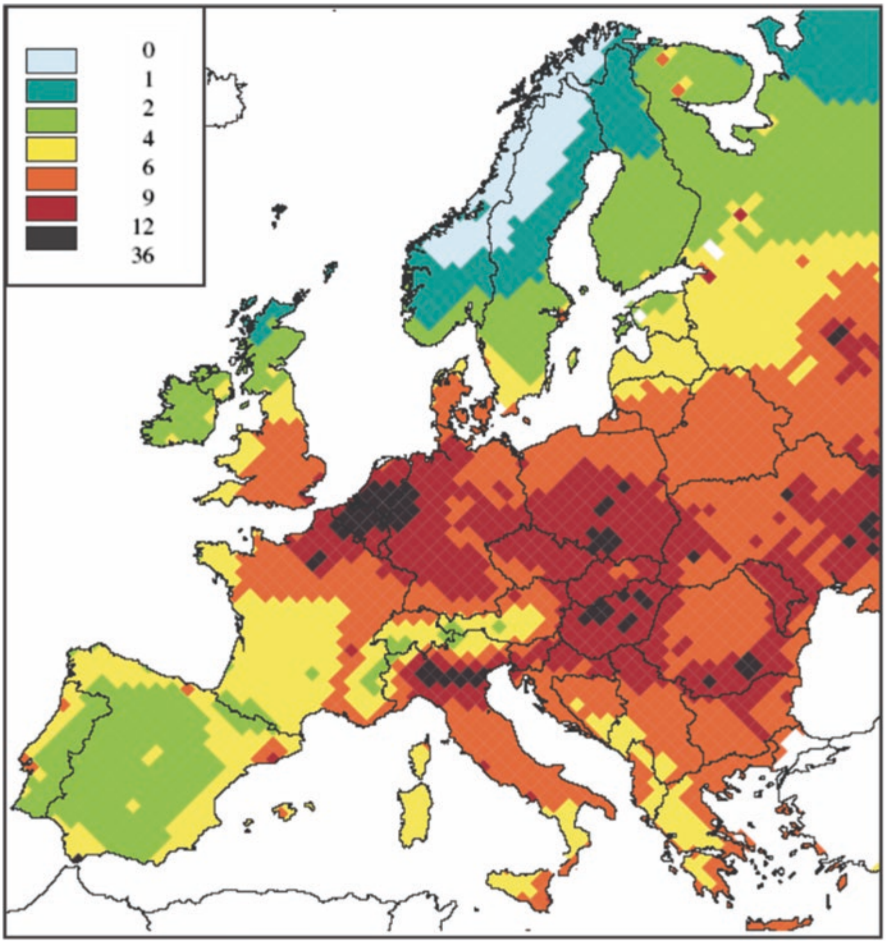

Fig. 2.6 Loss in statistical life expectancy in Europe in 2000 due to emissions of particles (PM2.5) (From the presentation "Kommissionens luftvårdsstrategi – CAFE: Fina partiklar men också de traditionella luftföroreningarna", Peringe Grennfelt IVL Svenska Miljöinstitutet Svensk Energi 27th of January 2005. Figure used with the author's permission.) in months

reduced by 1-3 years due to air emissions. In the three largest cities in Sweden the reduction is 6-9 months, while in the majority of Sweden it is 0-4 months (personal communication; Grennfelt 2009).

The concentration of ecosystem and human health impacts in areas with the highest level of economic activity per area unit in combination with the high economic costs in terms of human health impacts suggests that economically efficient policies for sustainable growth in Sweden and the EU would improve the competitive power in rural areas in Sweden in two ways:

1. Through payment for the production of ecosystems services such as the annual sink of around 170 million tonnes of carbon dioxide via photosynthesis in Swedish forests.
2. Through the competitive advantage of industries via the combination of resource and emission-efficient industrial plants located such that the negative pressure is zero or significantly lower compared with identical industrial plants located in areas with high economic activity per area unit with a corresponding high environmental and human health load (see Figs. 12 and 13; Hellstrand 1997 and 1998 treat this issue).

Incentives with the characteristics of the 4P principle would work via these two paths. At the same time, they would favour cost-efficient measures that help the adaptation of those urban/industrial regions to human health and ecosystems carrying capacity limits where they are now trespassed. This implies that the costs of such measures are allocated in those urban areas where the contribution to GDP will be somewhat lower when the ecosystem and human health impacts are internalised in the price mechanism, improving the environment and increasing expected average lifetime.

We suggest that the 4P principle works as a compass for societal processes resulting in sustainable development when complemented with sufficient maps of the sustainability landscape.

The five tools mentioned combined with the 4P principle express the system perspectives of Figs. 2.2 and 2.3, solve the major problems of Fig. 2.4 with regard to relevance for systems where life is a defining system characteristic, and thus have a high capacity to support increased sustainability performance of complex systems expressing the syndrome of complexity typical when life is a matter, i.e. sustainability (see Fig. 2.1).

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Chapter 3
Population Development, Demography and Historical Perspective

Erik Dahlquist

3.1 Population Development

During the 1950s and 1960s the big challenge was how to feed the growing population. The global population was approximately 3.5 billion, and the agricultural land was limited. How is it possible to feed all these people? There was no sign of reduced population growth.

Then, it can be interesting to remember a similar situation approximately 700–800 years ago in Europe. The population was growing, while the productivity in agriculture had stagnated. At that time the big plague helped solve some of the problems, by reducing the population dramatically. A few hundred years later major reforms were also made, increasing the crop yields in the fields. Thereby, the increased population could still achieve reasonable conditions.

Now, going back to the situation during the 1950s and 1960s: In Europe, we had the two big wars 1914–1919 and 1939–1945, where a 10th of millions of people were killed or died due to poor conditions and many countries were destroyed. In China, we had the "cultural revolution" and the "big step", leading to death by starvation and malnutrition all over China during the 1960s. In India, independence from the colonial UK came during the late 1940s, and in Africa some 10 years later and onwards from the UK as well as other countries like France and Portugal. All these dramatic events put a major difficulty to our politicians on how to get things running again.

In Europe, massive economic support from the US helped Western European countries to get up and running again, while Eastern Europe became part of the Soviet Union block. Still, economic growth took speed and proceeded for decades. In China, dramatic changes took place at the end of the 1970s, also giving strong economic growth, when Mao Tse-tung died and Deng Xiao-ping got the chance to

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Springer International Publishing AG 2017
E. Dahlquist, S. Hellstrand (eds.), *Natural Resources Available Today and in the Future*, DOI 10.1007/978-3-319-54263-8_3

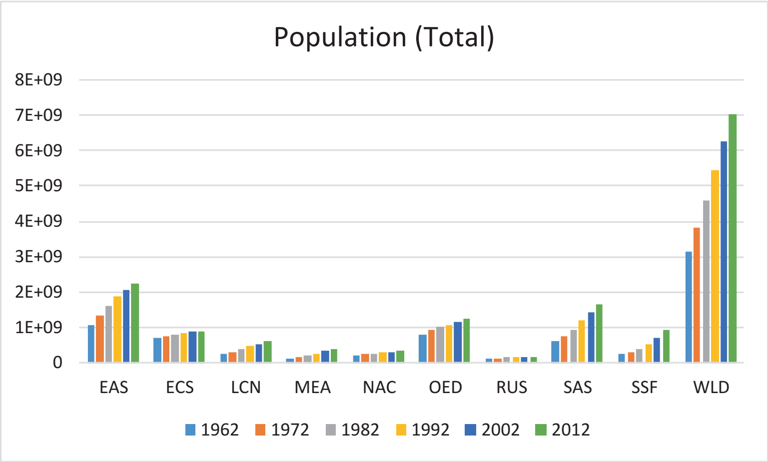

Fig. 3.1 Population development 1962–2012 in different regions and globally

introduce a kind of market economy. India started economic development as well. In reality, most of the Asian and South American countries succeeded in organizing themselves and achieved significant economic growth. Only in African countries, wars and different kind of riots still caused major difficulties to developing economic conditions, and thereby also the crop production.

In Fig. 3.1 we see the population development from 1962 to 2012. During those 50 years the population grew from approximately 3 billion to 7 billion people. The population more than doubled!

In some areas like East Asia, South Asia and Africa South of the Sahara the increase has been quite fast, while it has stagnated in Europe, North America and Russia.

The positive fact is that the population growth rate has declined as seen in Fig. 3.2.

During the 1960s, the annual growth rate was around 1.5–3% per year in most countries. In East Asia (EAS), the peak was during the 1970s, in the Middle East and North Africa (MEA), South Asia (SAS) and Sub Saharan Africa (SSF) during the 1980s, while in the rest of the regions including Europe and central Asia (ECS), Latin and Central America (LCN), North America (NAC) and Russia (RUS) the peak was during the 1960s.

We can see that the annual growth rate today is approximately 0.7% in East Asia, 0.2% in Europe, just above 1% in Latin America and South Asia, a little less than 1% in North America and almost zero in Russia. Still, it is quite high in the Middle East and North Africa with almost 2% and very high in Africa South of the Sahara with almost 3% at average. This means that we see a dramatic increase in population in most of Africa, but a stabilization in the rest of the world, with even a slight decrease in population in Europe and Russia.

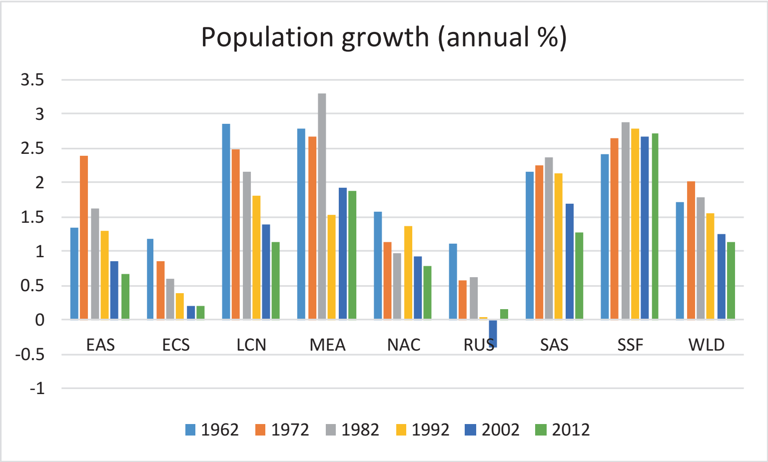

Fig. 3.2 Annual population growth rate in percent

During the last 10 years, we have also seen significant improvements in the economic conditions in Africa South of the Sahara in many countries. Many of the local wars have calmed down and political leadership has been less corrupt in several countries, leading to more infrastructure development of the countries. By introducing mobile phone nets people have been able to obtain more efficient communications. You can sell your products directly through the internet, make your payment through internet banking "without bank offices", learn about new technology etc. Local electricity production using photovoltaics (PV) has also lead to new local businesses etc.

This has made the situation look significantly better in many Sub Saharan countries, although there are still countries suffering from local wars and strong corruption. There are telling figures that money taken by a small group of influential people annually and placed in tax free countries may be significantly higher than the total financial development support from richer countries. Thus, a better distribution of wealth is a key issue, and the question is how to get responsibility for the majority from leaders in corrupt countries? Probably this has to be driven from inside the countries, and there is need for both a willingness from influential people as well as administrative competence and skills in communication to get "everyone" to follow.

At the same time as we have seen this increase in both population and increase in economic growth, we have also seen a strong increase in crop productivity. In Fig. 3.3 we see the increased production of cereals during the last 50 years in different regions.

In East Asia, South Asia and Latin and Central America the productivity has tripled. In the Middle East, Northern Africa and North America it has doubled. In Europe and Africa South of the Sahara it has increased by approximately 50%.

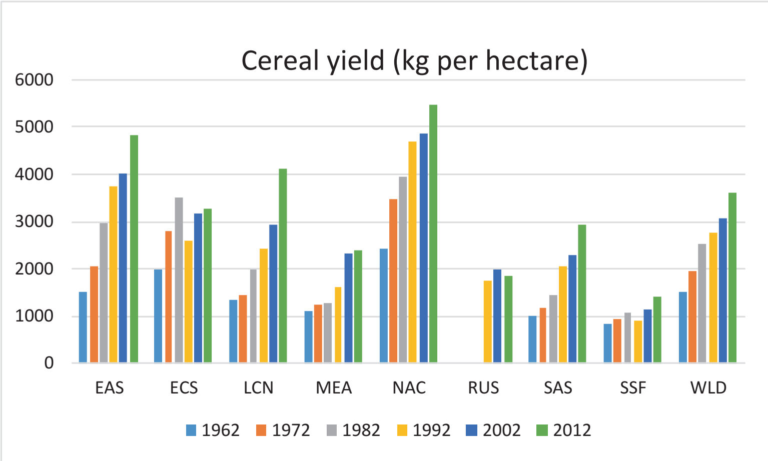

Fig. 3.3 Cereal yield development during the last 50 years

The major reasons are better quality of the seeds through selection of high productivity and draft resistant species, irrigation and addition of synthetic fertilizers. We have seen a real "farm revolution" due to this. If we look at the absolute values we can see that there is a significant potential for increased production per ha in most regions, but especially in Africa South of the Sahara where the productivity is extremely low in some areas, although the conditions should be generally quite good with respect to climate. Since the population in Africa is predicted to grow dramatically from approximately 1 billion today to around 2–4 billion during this century, this is really needed.

According to a UN prediction, Europe will reduce the total population from 742 million today to 640 million by 2100, while the Americas will increase from 981 to 1200 million, Asia from 4300 to 4700, and Africa from 1100 to 4200 according to an article by Vincent Nouyrigat [in Science and vie, February 2015, p 72–76]. The prediction is that Nigeria will have 914 million inhabitants by 2100, compared to 1085 million in China and 1546 million in India! The prediction also believes there may be more than 200 million in Tanzania, Democratic Republic of Congo, Niger, Uganda and Ethiopia. This is under the assumption that the birth per woman will stay higher than in most other parts of the world, which may be questionable. With this new (2015) UN prediction for 2100 we should have around 11 billion inhabitants by then, which is 1.5 billion higher than predicted just a few years ago by the UN. Today 29 African countries have > = 5 children per female, and the new figures come from a new way of calculating that assumes fewer deaths. We can compare the predictions to IIASA's (Austrian environmental institute) with 516 million in Nigeria by 2100 and 9 billion world-wide. IIASA believes we will have a maximum in 2070 with 9.4 billion, and then a slow reduction again, while the UN believes there will be a continuous increase even beyond 2100. If we are a bit critical, we should remember that increased living standard normally gives reduced birthrates quite quickly, so if the economy can improve, these predictions should be over-estimating the development in population growth. On the other hand, it is still to be proven whether the economic development would benefit everyone and not only a small group of "people in power", as has been seen so far over the last 50 years in many African countries.

If we now come back to the worries about food during the 1950s and 1960s, we can see that poverty and starvation is significantly lower globally today; also in absolute figures compared to then, although it is 7 billion compared to 3 billion in population. By improving agriculture, it is also possible to balance a large population.

We also need to develop solutions for long term sustainability in agriculture, so that soil is not destroyed and eroded. Today there is a tendency to build cities where we have the best farmland, and a question is how to avoid this. Perhaps we can also use buildings for crop production much more. This is of special interest, since we see concurrently population growth and a transfer from rural areas to urban areas.

In Figs. 3.4, 3.5 and 3.6 we see the development of populations in urban areas. Fig. 3.4 shows the development has been high everywhere, although a bit lower in Europe, North America and Russia compared to the rest of the world.

In Fig. 3.5 we can see that more than 50% of the population already lived in urban areas in 1962 in Europe, Latin and Central America, North America and Russia, but today all populations except for South Asia and Africa South of the Sahara live mostly in urban areas (>50%). This means that fewer people are producing the food. If we look at developed countries the trend has been that the number of people working as farmers has been reduced continuously over the last 200 years, and often is only 2–3% of the population today. Still, the production is much higher than earlier due to more efficient production methods with huge tractors, irrigation and chemical fertilizers.

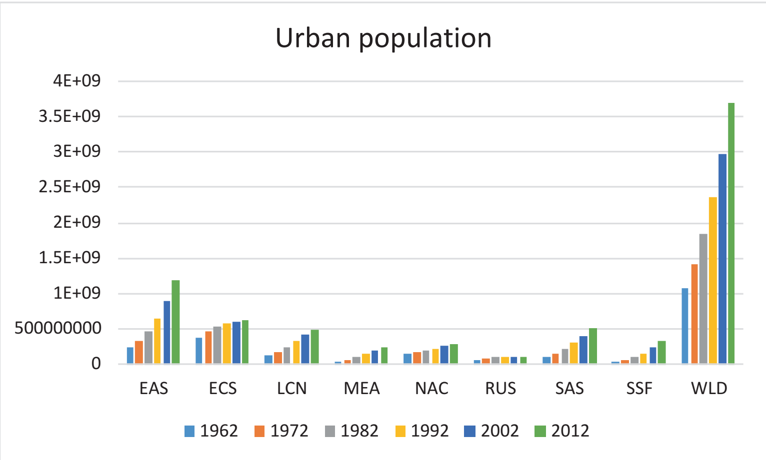

Fig. 3.4 Urban population development in number of people in the different geographic regions

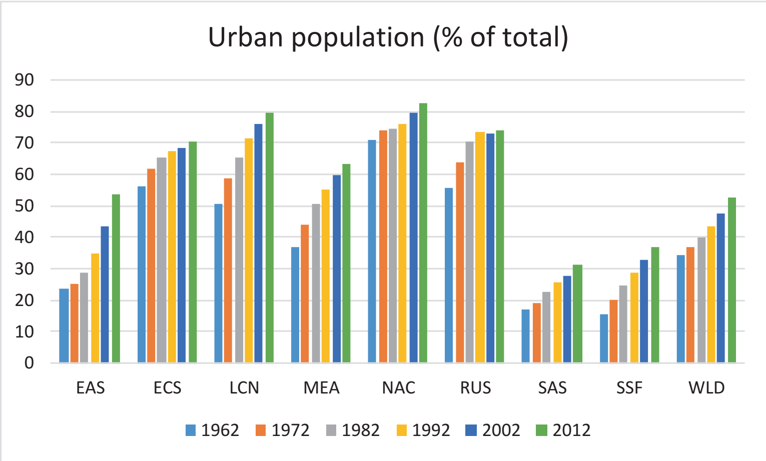

Fig. 3.5 The development of urban population in percent of all people in the different regions

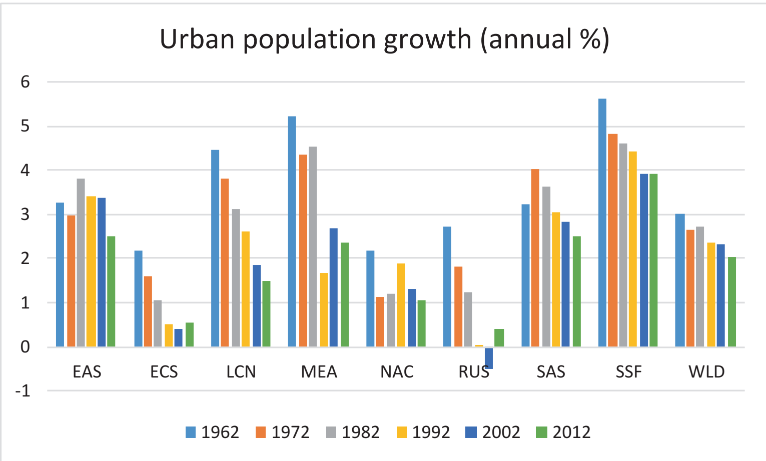

Fig. 3.6 Growth rate of population in urban areas from 1962 to 2012

If we go back 500–1000 years a lot of the food in urban areas was actually produced inside the cities. Today, there are discussions about taking up this trend and growing more food in cities, thereby reducing the pressure on those producing the food at the country side.

If we go back to the development of populations in urban areas we can see that although the percentage of the population is growing, we also see a reduction of the growth rate in most areas, especially in Europe and Russia (see Fig. 3.6).

Of course the population in rural areas is reduced correspondingly as seen in Fig. 3.7.

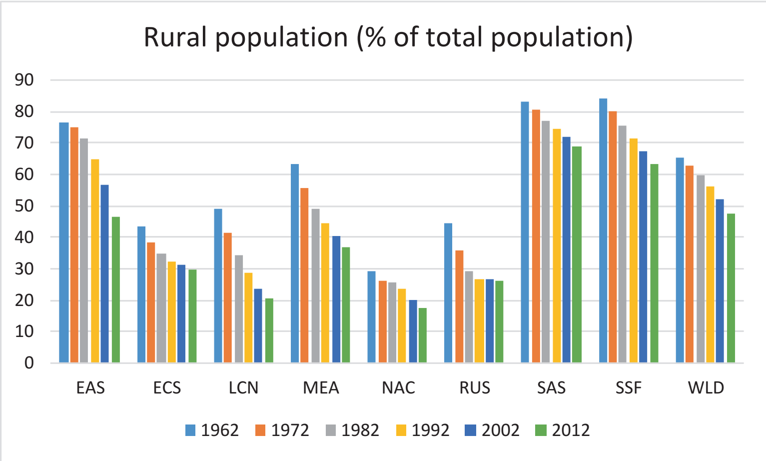

Fig. 3.7 Development of population in rural areas in different geographic regions as a percentage of the total population

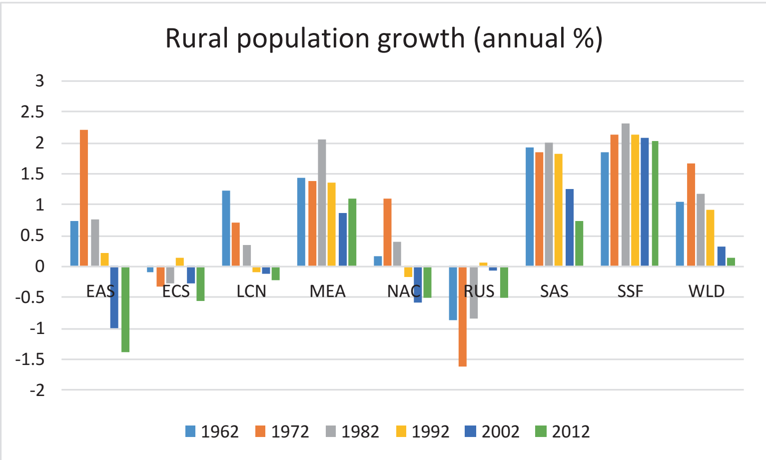

Fig. 3.8 Development of the rural population in the different geographic regions from 1962 to 2012 as annual percentage increase

Due to the migration from rural areas to urban areas we also see a decrease in the population as seen in Fig. 3.8.

The total number of people varies quite a lot between different regions (see Fig. 3.9). In South Asia, it has gone from 120 to 350 people per square km of land area from 1962 to 2012 while countries like Russia have a very low population density as well as North America, although a bit higher. Thus, the pressure on the land is very high in some regions and causes potential problems to sustain agriculture at a level that can feed the population locally. On the other hand, a lot of small

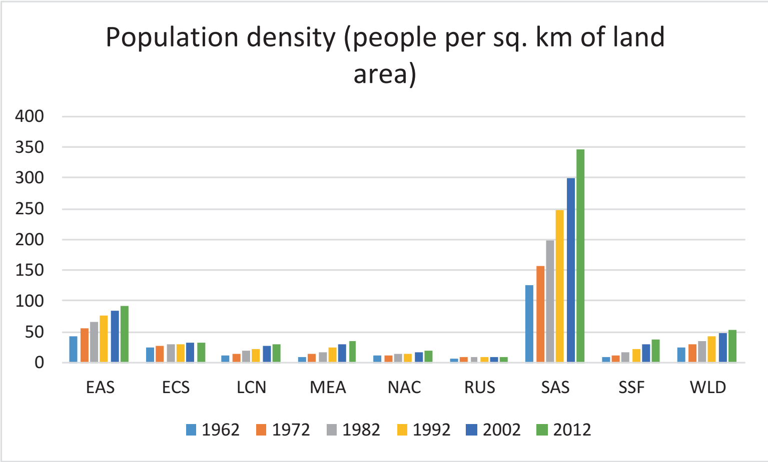

Fig. 3.9 Population density development in the different geographic regions during 1962 to 2012

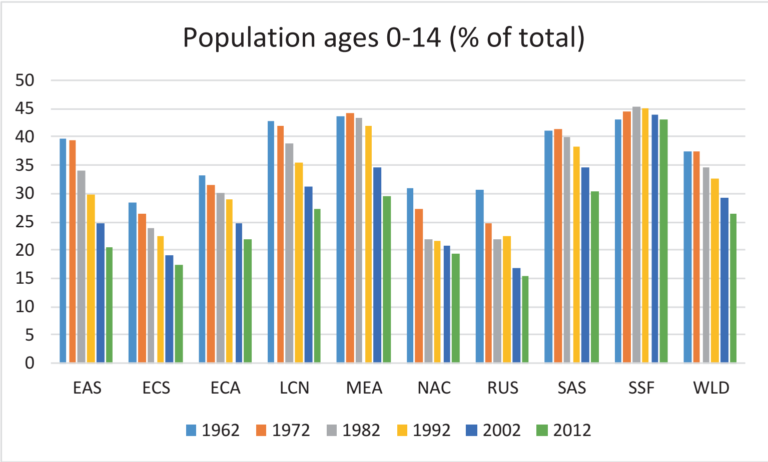

Fig. 3.10 The amount of children aged 0–14 years old in the different geographic regions 1962–2012 as a percentage of the total population

garden farms are very productive, and can compensate for the low amount of area per person. The density in India is ~10 times higher than the global average.

Another interesting factor is the demography of the population with respect to ages of the population. In Figs. 3.10, 3.11, 3.12, 3.13 and 3.14 we see the development of population in different ages in the different regions. In Fig. 3.9 we have the children aged 0–14 years, as a percentage of the total population. Due to reduced birth rate in most countries, we also see a corresponding decrease in the percentage of children. It is only in Sub-Saharan Africa we still see the same percentage today as 50 years ago.

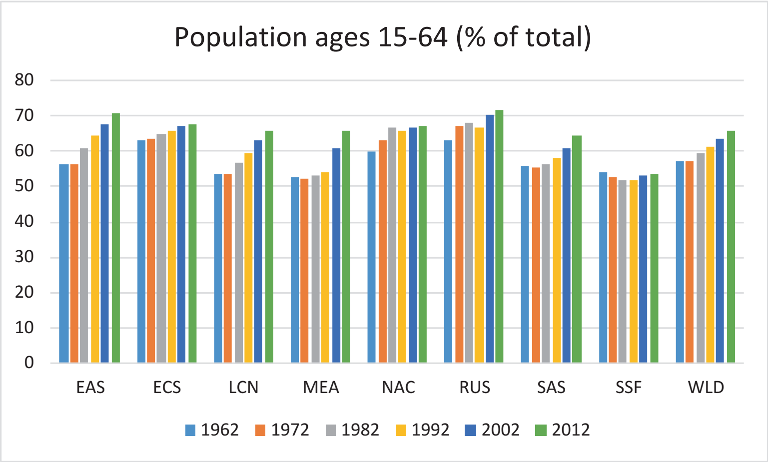

Fig. 3.11 Development of population in the age 15 to 64 years in the different regions from 1962 to 2012 as a percentage of the total population

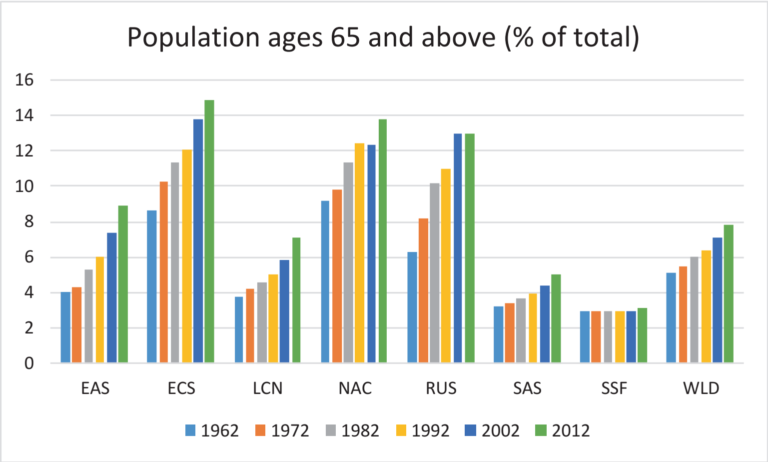

Fig. 3.12 The development of people 65 years old or older from 1962 to 2012 in the different geographic regions as a percentage of the total population

In 1962 the global average was almost 40%, while today it is more like 25%. The advantage is that there will be fewer mouths to feed in the future. In the age 15–64 years we see (Fig. 3.11) a slight increase from 57 to 65%. This is good, as this category is the one that should produce what we need with respect to both food and everything else. This is especially true as there is a wish to stop children working, and instead go to school to get proper education.

Finally, we can see that the work force is increasing a little, children are decreasing quite a lot and elder people are also increasing significantly (Fig. 3.12). This means

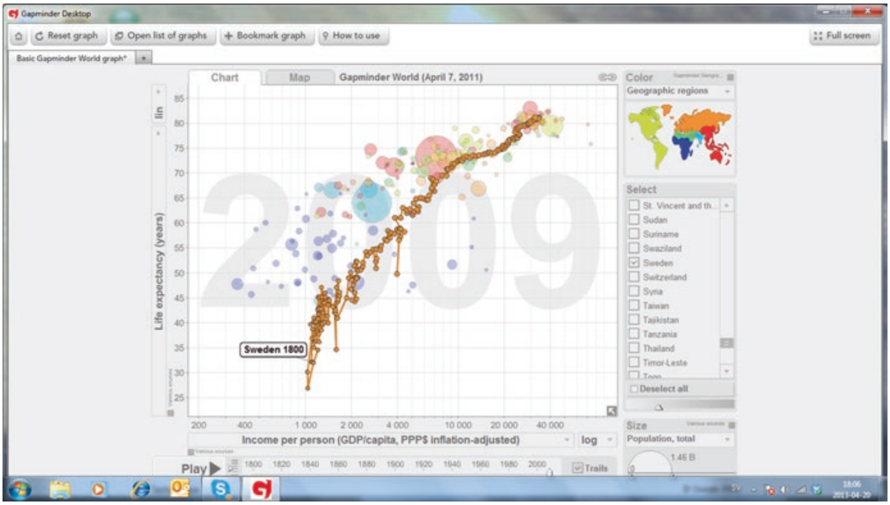

Fig. 3.13 Life expectancy development as a function of both time and economic development measured as income per capita in Sweden from 1800 to 2009 (From Gapminder, built on World Ban data)

Fig. 3.14 Life expectancy as a function of per capita income globally 2009 (From Gapminder, built on World Ban data)

that if we keep the pension age at 55–65 years, as is the case in most countries, there will be a problem to sustain a reasonable amount of pension money long term.

Since people also are healthier at higher ages, we can predict an increased retirement age to match this. If we compare for instance 1916 to 2016: In Sweden when the general pension was introduced in 1916 the average age of death was around 57–58 years and the pension age 67 years. Today, the average life expectancy is 80 years for males and 84 for women, while the retirement age is flexible between 61 and 70 years, but most people retire at 65 years. The cost to cover the additional 15–20 years for retired peoples is very much higher than the minor cost for the system in 1916. Thus, some years ago a system was introduced where everyone pays into their own account, and money then is paid out in relation to the amount collected over the whole life. You then can select to get a higher amount during a few years or a lower amount during a large number of years. As life expectancy is increased even further it will mean lower annual payment as what you have earned is paid out over more years. Thus, it is discussed to make it possible to work until 75 instead. In some countries it is even more complicated, like in Greece where people can retire at around 55 if employed by the government, while the privately employed work longer. This is assumed to be one of the major problems for the Greece economy right now, as it is difficult to collect money from the population to cover these costs. The situation is similar in many other countries, and is causing big problems in many governments, as the income is not in balance with the expenditures.

Life expectancy depends on many things, but it is interesting to note that it increases year by year, and has done so for several decades, even under harsh times. An example is Sweden, where there were wars during the eighteenth century, and starvation during the nineteenth but strong economic development during the twentieth century.

In Fig. 3.13 we see that life expectancy was only around 30 years in 1800, but has increased steadily ever since to reach the 80–84 years today for males–females respectively. There are still countries where life expectancy is very low, and even relatively wealthy countries like Russia had very low life expectancy—around 58 years—as late as the mid-1990s for males, primarily due to a culture of drinking extreme amounts of strong alcohol, vodka, and smoking heavily.

Otherwise, the trend is similar in most countries, although with parallel curves as the take-off has come at different times. It is interesting to note that the percentage of people 65 and above has been constant in Africa South of the Sahara throughout the period 1962 to 2012, although strongly increasing in all other regions. This means that the potential for improvements is high if the increased economic conditions proceed as we have seen over the last 10 years.

As can be seen in Fig. 3.13 the correlation between economic development and life expectancy is strong in Sweden. In Fig. 3.14 we see how life expectancy in 2009 correlates to income per capita in 2009 globally. The countries have a color representing the geographic region and a diameter correlating to the population. It can be seen that there is a strong correlation between income per capita and life expectancy, although with some exceptions. In most cases, the exceptions are related to poor distribution of wealth as the income is just total national income divided by total number of people.

We also see a strong correlation between the life expectancy and the income per capita. In the left lower corner, we see that most of the countries are in Africa South

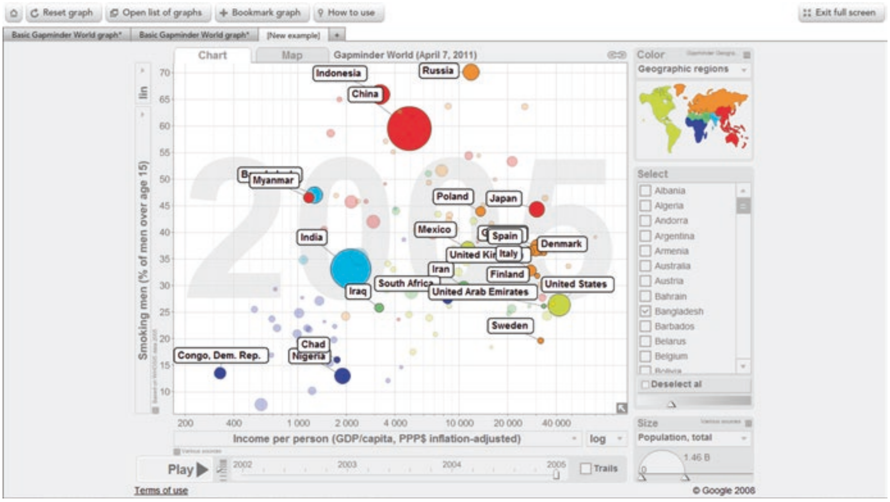

Fig. 3.15 Percentage of smoking men as a function of income per capita

of the Sahara. The colors relate to different regions as seen in the world map in the upper right corner of the figure (from Gapminder).

Some factors greatly affect life expectancy. One specific factor is smoking, which is considered to lower life expectancy as much as HIV in developed countries with medical treatment. This means that smoking reduces life expectancy within the range of 5 years statistically. It does not mean that smoking is dangerous for everyone. Here, we also see a big difference between different individuals. Some are more tolerant to smoking than others. This is also the case for drinking alcohol; where some become addicted to alcohol, while others can live drinking no more than what is healthy.

From Fig. 3.15 we can see that there is no strict correlation between income and the percentage of smokers among men. Other factors like habits and advertising are more important today than income. Therefore, many countries try to change the habits and make advertisements for smoking illegal. Unfortunately, cigarette companies have a tendency to increase the advertisements in countries where it is not forbidden when they get problems in countries with bans on smoking in offices, restaurants etc., and not allowing ads. The same is the situation for alcohol, which also causes a significant decrease of life expectancy for those drinking too much.

For other types of drugs like heroin or other opiates as well as Cannabis and now also many synthetic drugs and steroids, health issues and life expectancy can be seriously affected in a negative way; and this also goes for the private economy for those addicted as well as for society to take care of addicts. Very often drugs cause a lot of indirect problems like burglary and robbery when addicts need money to finance their misuse of the different substances. This is a problem in most countries, and unfortunately does not seem to diminish significantly although many actions have been taken to try to reduce the misuse.

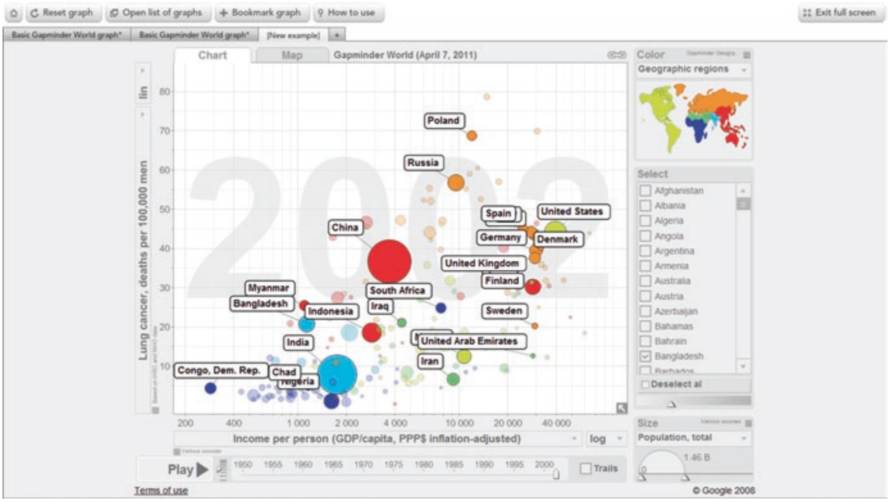

Fig. 3.16 Deaths in lung cancer for males per 100,000 inhabitants as a function of income per capita

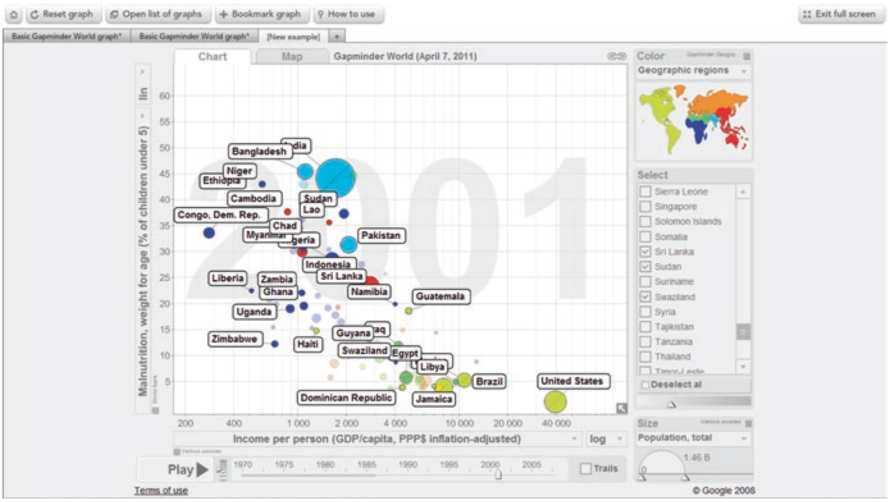

Fig. 3.17 Malnutrition as a function of income 2001

In Fig. 3.16 we see the deaths in lung cancer for men per 100,000 inhabitants as a function of income per capita. We can see some correlation, although not very strong. Smoking is a problem for both rich and poor!

Malnutrition is another important factor for reduction of life expectancy. In Figs. 3.17 and 3.18 we can see a reduction in malnutrition from 2001 to 2007. The decrease seen is significant, and the trend proceeds in the same direction. This means that fewer people are starving year by year. To some extent this is due to

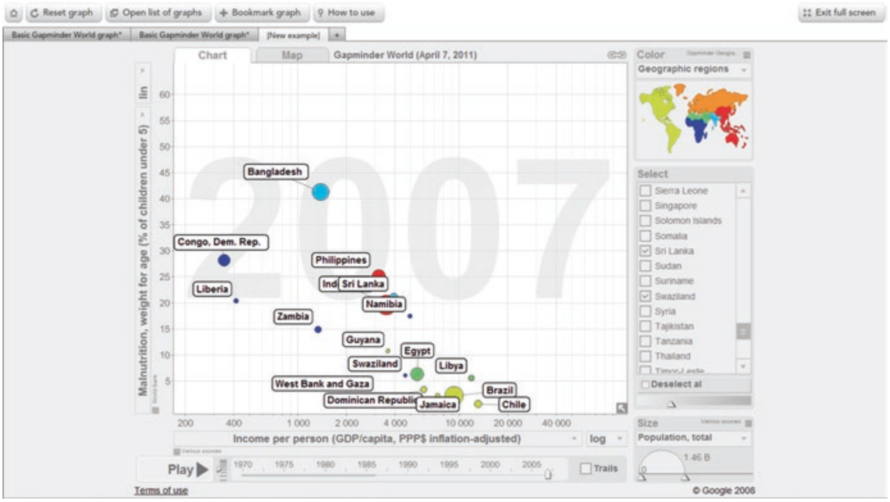

Fig. 3.18 Malnutrition as a function of income per capita 2007

better distribution of wealth, but also because storages of food are built and food distributed to areas where harvest is poor. Unfortunately, those who have something to sell are affected negatively since normal market mechanisms are destroyed, at least temporarily, when food comes for free from outside. It is very difficult to have robust systems that work in the same way all the time and everywhere!

3.1.1 Conclusions

From this overview we can see that the population of the world has doubled between 1962 and 2012, but the rate of population increase has slowed down to reasonable levels everywhere except in Africa, and especially south of the Sahara. During the same time period, the economic development has generally been strong in these countries; and thereby poverty is less today than in 1962, although the population has more than doubled. One reason is better agricultural methods, increasing the harvests strongly per hectare. This has led to decreased early deaths and thereby increased life expectancy. In Africa South of the Sahara we have the exception from these trends as economic development, harvests and life expectancy have not followed the rest of the world. More positive signs from here during the last 10 years are due to less warfare as well as more stable governments with stronger will to promote the welfare for the population and not only the rulers. This means less corruption. This has led to strong development of economic conditions in many countries, although there are still significant problems in some countries like Somalia, Sudan, Republic of Congo and Zimbabwe.

One of the new problems arising is how to handle a large population of elder people. As retirement age is normally set in a regulatory framework, people are principally not allowed to stay at work after a certain age, such as 60 years for males and 55 years for females in China. There are similar ages for retirement in many other countries causing problems as the money needed for pensions, of especially formal governmental employees, has to be covered by taxes, and we are reaching levels where increased tax is no longer an alternative. This means that we need to modify the pension systems due to increased life expectancy, which has turned out to be rather difficult. On the other hand, we now see a general stabilization of the global population and predictions now state that we should reach a level of some 9–10 billion at the end of this century, but thereafter slowly decrease again.

The question then will be how to sustain our capability to produce the crops and meat needed for this population long term. Many of the methods used rely on limited resources like phosphate. How can we recycle this in an efficient way? The use of fossil fuels is also causing problems with climate change, which can influence productivity etc.

From a demographic perspective this is important. It is also important to consider the distribution of wealth between different population groups and different age groups, to sustain a stabile society. Extreme groups trying to force everyone else to follow their rules and implementing self-bombing etc. as tools will cause at least local problems, while conflicts between larger groups or regions can be even more problematic. No one (almost) wants a new cold war or even worse—a new world war!

Strong economic integration is probably the best way of reducing risks for this, as no one wants to risk their own economy if it is possible to avoid. Poor economic development is a threat to this stability and the huge transfer of un-wealthy people trying to make a better life in some more wealthy part of the world is also affecting the demography significantly in many countries. This can give both positive and negative effects, but the trend towards more opposition to immigration in many countries is a potential threat to stability. The huge number of refugees leaving Syria in 2015–2016 reflects the problem arising when resources are limited and different groups try to control the resources, and at the same time claim to represent something higher, like religious beliefs. The major powers like Russia, the US, the EU, Saudi Arabia and Iran all have different interests, and thereby support different groups, until all resources are depleted and the war stops by exhaustion. So even if we see general positive developments, we will also see big local problems during the coming decades.

3.2 Historical Perspective

We can look at the historical development of agriculture in a bit longer time perspective. If we go back some 10,500 years we can see the first cities in the Middle East, where the earliest agriculture can also be seen. Recent research indicates that the first temples were probably built in Turkey and farming then started around these. It was simple farming as a complement to just gathering crops and hunting. Around some 8000 years ago agriculture spread into Europe.

Approximately 6000 years ago agriculture had spread all the way to the British Isles and Scandinavia. Here, we had an agriculture where mostly small areas with trees were burned, and thereafter planted with some crops. After a harvest they moved on to utilize another area and the used was left for recovery. This gave a small additional food contribution. The Romans started to develop farming further and tried to find both better crops and better methods to increase the harvests. Distribution of manure as a nutrient was one thing Roman scientists were already trying to optimize some 2000 years ago.

The population in Europe grew up to around 540 a.c. In 536 a.c. an enormous volcanic eruption is thought to have occurred. In both European and Chinese documentation, you can read that the sun was covered for 3 years, and the crop production went down dramatically, due to the climate change introduced during approximately one decade. This was shown by Andersen and Berglund (1994) where they compared ratio tree pollen to non-tree pollen. There was less non-tree pollen in most areas in central Europe 500–600 a.c compared to 150–200 a.c., while it increased in Scandinavia. At the British Isles there was increase at some spots, but decrease at others.

After the volcanic eruption in 536 a.c., in China, authors wrote about the sun disappearing for several years. In the city Ching south of Shandong snow was reported in July and August 536–537! Some 70–80% of the population probably died in the area north of Yellow river due to starvation. It is known that Northern China, Mongolia, parts of Siberia and Eastern Europe got difficult drafts as well, and this pushed an increase of big population movements from Eastern Europe towards the west.

In 541 a.c., the first cases of a disease, called Justinian plague, were spreading over Europe, and especially around the Mediterranean area (Charpentier-Lungqvist Fredrik 2009). The combination of low food production and the disease is believed to have reduced the European population strongly; most likely also in other countries in the northern countries, although it is not documented that well.

Gräslund (1980) believes this cold period was the reason for the Fimbul Winter myth that was part of the ASA-god-belief in northern Europe after this (with Odin, Thor etc).

In 1086 Wilhelm the Conqueror created the Domesday Book, where all farmers and land owners were registered. From this, estimates state that England (without Wales and Scotland) had 1.1 million inhabitants at the end of the eleventh century. The population then increased to some 3.7 million in the beginning of the fourteenth century, and the plague reduced the population to around 2.25 million at the end of the century. An estimate made in 1328 based on who paid taxes showed that France had 16–20 million people. In 1789, France had approximately 25 million (significantly larger). If we look at all of Europe around 1330 there were approximately 60 million, and thus 1/3 in France! Italy had approximately 10 million, the Pyrenean peninsula 9 million and Germany 8 million (Nordberg Mikael 1984).

It is not possible to get any exact figures, but what can be seen is that a lot of agricultural land became "wild", and bushes and trees took over a lot of previously used farmland. In some areas there were almost no people left, while in other areas the remaining people had to concentrate on the closest, best soils for agriculture, and with more meat production instead of crops for human food use. After this it took several hundred years until the population started to increase again and agriculture with crop production also increased. Around 1350–1370 we had the plague which killed a lot of the European population again, and once more the intense farming area was reduced. Once more animal production took over again the need for crops as human food decreased. As mostly weaker people died in the plague, those surviving were healthier and the life expectancy significantly increased. Before the plague only 10% lived to the age of 70, while after around 25% in Great Britain reached that age. The reduction of population gave the people previously working for noble men an opportunity to run their own farms, since the price of land decreased due to a large surplus available from the deceased. The salaries also increased for those working for noble men, since the number of available farm workers decreased, as the population of the British Isles was reduced by half.

Before the plague hit Europe it hit China and India, and possibly it came from central Asia to the other parts of the world with black rats. In China, there are estimates that 90% of the population died in some areas due to the plague in the beginning of the fourteenth century (Alnaes Karsten 2004).

Later on there were extensive wars during the mid-seventeenth century in Germany and the Napoleon wars at the end of the eighteenth century in central Europe. Both had a large impact on agriculture.

Farming developed substantially from the late sixteenth century, first in Holland and later spreading all across Europe over 300 years, until the most remote areas were covered in the beginning of the twentieth century in Northern Scandinavia and Eastern Europe. First, the Dutch developed much more intense animal breading where crops were used as fodder, instead of cattle only eating grass in the out-lands. Later, new crops like potato and corn as well as sequences of different crops including nitrogen fixating lay crops to increase nitrogen content, and thereby increase the productivity, were introduced. During the eighteenth century aristocrats took over a lot of the farmland and had "arrendators" to produce the food. By having larger areas the efficiency increased. In France on the other hand, the revolution in the late eighteenth century gave the farmers a stronger situation, and the enlargement of the farms slowed down. Still, the new methods for increased production spread from Holland to the British Isles to France and northern Italy and up to Germany, and from there further in all directions.

In Sweden, statistics about crop production started being gathered during the eighteenth century. First, local priests got the task, but as they normally underestimated the production (figures given by the strong farmers, who had to pay tax in relation to production!) the responsibility was transferred to local governors in 1822. The farmers in Sweden mostly either owned the land themselves or used government owned land and in both cases paid tax to the government. Only 1/3 of the land was owned by noble people, who did not pay tax to the government. On the

Table 3.1 Land ownership and tax payment

	Farmers own land (%)	Tax to government (%)	Noble owned land (%)
1700	32	36	32
1772	47	20	33
1815	53	15	32

Table 3.2 Production of crops in Sweden (Gadd et al. 1999)

	Cereal, pea, bean	Potato	Pure cereal
1802	1,048,241 barrels = 100	53,631 barrels =100	899,865 = 100
1820	120	449	126
1822	131	652	141
1860	228	2370	255

other hand, the farmers paid tax to the noble people instead. The distribution between different ownership (Emanuelsson, 2009) is seen in Table 3.1.

In 1790, only half of the area compared to today was arable land. This is because a lot of land was only used 1 year, and then not again for several years. In 1800, the harvest was typically 800 kg cereal/ha (Hannerberg 1971) where we today produce approximately 5000 kg/ha. Using more intense farming, the production is more than 10 times higher today at the same land area. Much of the land was used for animals as graze land, with relatively low productivity. A typical cow produced 600 kg milk/year around 1790, while 9000 – 10,000 kg/year today.

During the eighteenth century, the potato started to become important in Europe, and "took off" during the first half of the nineteenth century. Twice as much food could be produced at the same land area now, which gave a kick to population development. On the other hand, the risks increased and in, e.g. Ireland poor production due to mold some years caused millions of people to die due to starvation. Generally, we can say that as new mechanical equipment developed, such as steel plows and threshing machines, use of synthetic fertilizers and other means became important for improvement of the yield. As the production methods were improved the farming at very small slots, that had become typical in most parts of Europe due to heritage, became inefficient. Reforms were made to make larger units, making it easy to use the mechanical equipment efficiently. This resulted in production increase.

In Table 3.2 below production figures for different crops according to these measurements and estimates can be seen.

During the same period, the population increased from 2.35 million in 1802 to 3.86 million in 1860; 64%. Obviously, the increased food production was much higher than the population increase. The distribution of the wealth was still not that good, and therefore many poor people emigrated to the US during this time period. The population further increased to 4.1 million in 1865, 6 million in 1923, 7 million in 1950, 8 million in 1969, 9.7 million in 2014 and 10 million 2016. During the nineteenth century, farms started to practice rotation farming with different crops different years in a structured way. By using crops fixating nitrogen from air the soil was improved from 1 year to the next, and the production greatly increased. Use of lay crops (with clover + grass) made a dramatic change as did the start of adding phosphate from ground bones; Thomas phosphate from iron mining and later from mines in, e.g. Marocco/Spanish Sahara.

This gave a tremendous increase in food production in relation to earlier, and thereby the population also increased a lot during the last 200–300 years. The example from Sweden is representative for many European countries.

The next strong increase in production took place during the past 50 years when synthetic fertilizers, new high yield species and irrigation helped double the production per ha as shown in the previous chapter.

The industrial revolution during the eighteenth century demanded at first a lot of charcoal produced from tree-shoots driving towards this type of forest, but as stone coal started to be used the forests instead became more of the high tree type. This also made a strong change in the landscape. During the late nineteenth century, synthetic fertilizers became important in central Europe, starting in the most industrialized areas. In reality the term synthetic fertilizer is not quite correct as it included import of, e.g. guano from South America. Phosphate was often extracted from animal bones, which were dissolved in sulfuric acid. Also, Thomas Phosphate from iron production was utilized. One crop that was favoured a lot by these new fertilizers was sugar beets, which found a strong increase during the late nineteenth century. Also, a lot of humid areas were drained and thereby a lot of peat was transferred into farmland. A lot of fodder for animals was produced here, and thereby animal production was increased significantly.

3.2.1 Food Development

The most common food was bread during the period from the first millennium to the nineteenth century. In northern Europe, raw oats and barley dominated, while in southern Europe it was wheat and consegale. Approximately 90% of the food calories were estimated to come from bread. To this we add cabbage, carrots, onion, spinach, peas, beans, lentils and spices. The vegetables were normally cooked in soups. During the period after the plagues, meat became more common and around the fifteenth to sixteenth century high figures were noted, around 100–300 g meat per person a day in some cities like Berlin in 1397. Also, in the British Isles meat consumptions increased a lot which correlates with a strong increase in production of wool from sheep. The export of wool doubled between 1399 and 1475, which means that the number of sheep also doubled.

In some areas like India meat is not very common, and vegetarians dominate. Here, also strong spices are used as preservatives, while salt and sugar are used in other areas. A very high concentration of sugar is common in Turkey and Iran for instance, which is probably due to the good preservative properties. Many countries produce jam this way. It is worth mentioning that this method is also used to preserve bacteria, which neither die nor grow when the sugar content is above 25%.

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Worldbank Development indicators, down loaded 2015 and 2016

Chapter 4
Biologic Resources

Stefan Hellstrand and Erik Dahlquist

4.1 Introduction

In this chapter we discuss available biological resources through agriculture and forestry. We make use of the structure given by Figs. 2.2 and 2.3. This implies that we start with a presentation of the natural capital generating the fluxes of ecosystem services from agriculture and forestry, i.e. agricultural and forestry land. After that we provide information about some of the major inputs, such as nitrogen and phosphorus fertilisers, biocides and water (irrigation). Using information about the natural capital land, we show the results in the form of produced vegetal products, animal products and wood products. We present information about global levels and trends of some major geographic regions. Thus, so far we presented the production system determining the supply of some major biological resources and some ecosystem services of crucial importance for human wellbeing; soon we will give an overview of the demand on the same resources.

In 2012, the total global forest area was 2011 40 184 163 km^2. The total agricultural area globally was 49 052 958 km^2. The total land area of all countries was 129 710 427 km^2 by 2012. Global surface area was 134 289 915 km^2 in 2012. Of this 703 114 467 ha was for cereal production, or 7 out of 130 million km^2.

In 2010, the total CH_4 emissions were 7 515 150 as kton CO_2 equivalents. Of this 2 943 583 kton CO_2 equivalents was from the energy sector. Nitrous oxide emissions calculated as CO_2 equivalents were 278 375 as thousand metric tons. PFC gas

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Springer International Publishing AG 2017
E. Dahlquist, S. Hellstrand (eds.), *Natural Resources Available Today and in the Future*, DOI 10.1007/978-3-319-54263-8_4

emissions (thousand metric tons of CO_2 equivalent) were 100 514 in 2005 which is the last data measured globally by the UN.

Patzek and Pimentel (2005) performed studies around thermodynamics related to production of biomass, and use of it.

We found some confusion in recent scientific literature affecting land-use policies from regional and national authorities in Sweden, up to the level of IPCC. Thus, in scientific contributions up to the level of articles in Science and Nature, substantial weaknesses are found when compared to the understanding of the same production systems in agricultural sciences within the fields of crop production, animal husbandry, farming systems and agroecology. There are also conflicts within these articles and the measures proposed in the policy-sphere based on their internal rationality, and the understanding of linked ecological-economic systems within systems ecology and applied environmental sciences. Basically, this reflects an understanding of agricultural systems in their ecological, economic and social contexts according to Fig. 2.4. Therefore, there is a need to present some basic concepts, terms and knowledge of agricultural and forestry systems from the disciplines that deliver the competence of excellence regarding them, in a sustainability context.

That presentation is started in Chap. 2.

Some of the possible societal consequences if land-use policies are not based on the competence of excellence regarding concerned systems are presented.

The data we use are mainly from FAOstat and World Bank indicators. We follow their way of structuring and grouping nations as well as of crops and products. The limits regarding available data in this source of official statistics are reflected by natural reasons in this text as well.

4.1.1 Overview Over Land Use

In Fig. 4.1 we see the distribution of land area between the different regions in km^2.

A more interesting piece of information is the area used for agriculture and how this has changed over the last 50 years. This is seen in Fig. 4.2.

As we can see the most populous regions, East Asia and South Asia, have the highest % agricultural land area of the total, > 50%, while the rest have 30–40% generally. It is interesting to see that Africa South of the Sahara has a high percentage, but the productivity per ha is significantly lower than in the other regions.

Agriculture area includes both intensive and extensive use, and the intensive use for cereal production is shown in Fig. 4.3 and the percentage of permanent crop land in Fig. 4.4.

In Fig. 4.4 we see the percentage for the different regions, and in Fig. 4.5 we isolate some very important countries from an agricultural perspective.

We can see that the percentage of permanent crop land increased a lot in most regions accept in the EU, North America and Russia. This is positive, as we at the same time see a strong increase in the productivity per ha as well. Especially, in China it is dramatic, but we should remember that the turmoil during the 1950–70s gave very low efficiency, and thus the potential for increase was very high! The

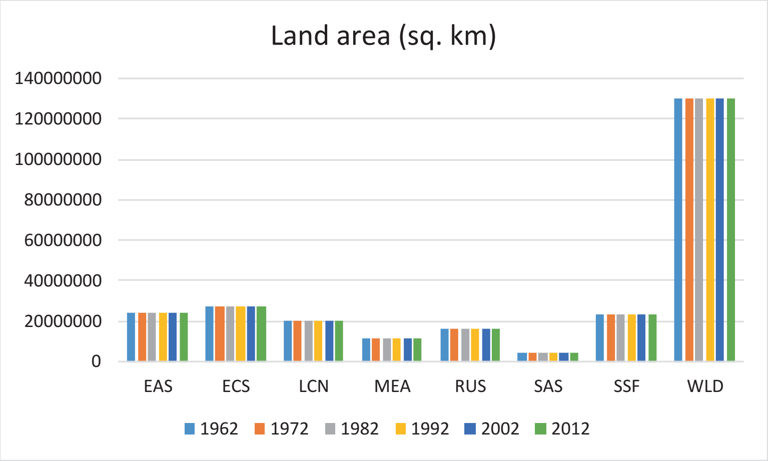

Fig. 4.1 Land area distribution between different regions

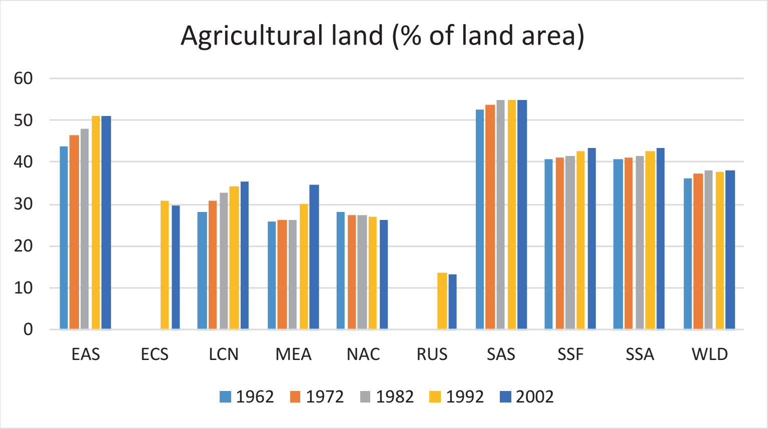

Fig. 4.2 Land area used for agriculture distributed over the different regions as % of the total land area

decrease in the EU is more problematic. The reason is to a large extent due to low profitability in producing food as a farmer. Thus, often relatively good intensive farming is turned into more extensive use.

The good thing is that this land could be reused for crop production sometime in the future if the economic conditions are changed.

After this overview we now will go into more details.

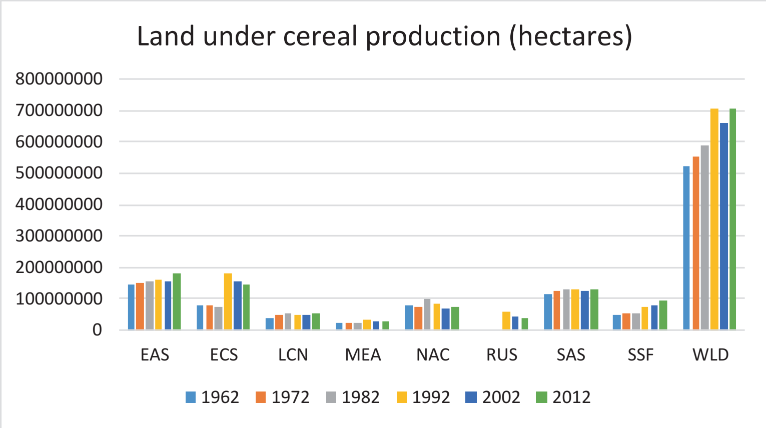

Fig. 4.3 The area in ha within each region used for cereal production

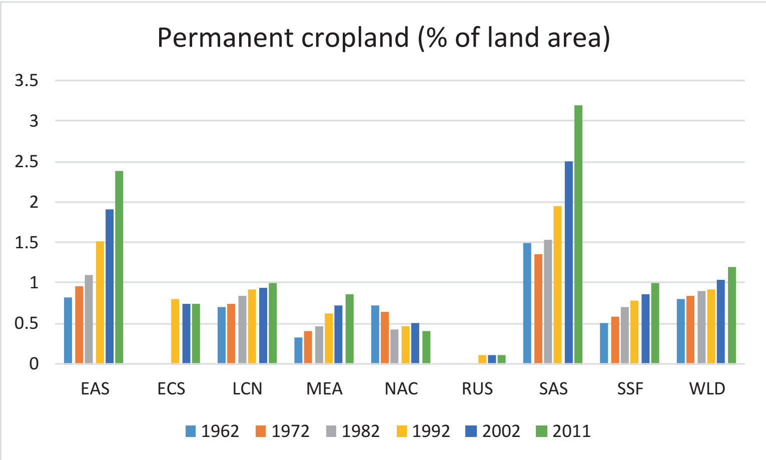

Fig. 4.4 Percentage of the total land area in each region that is permanent cop land

4.2 Natural Capital Land

4.2.1 Global Distribution

Figure 4.6 gives an overview of the distribution of land globally.

On the global scale, area equipped for irrigation in 2012 was 23% of total area of arable land.

The *definition of arable land* is the land under temporary agricultural crops (multiple-cropped areas are counted only once), temporary meadows for mowing or

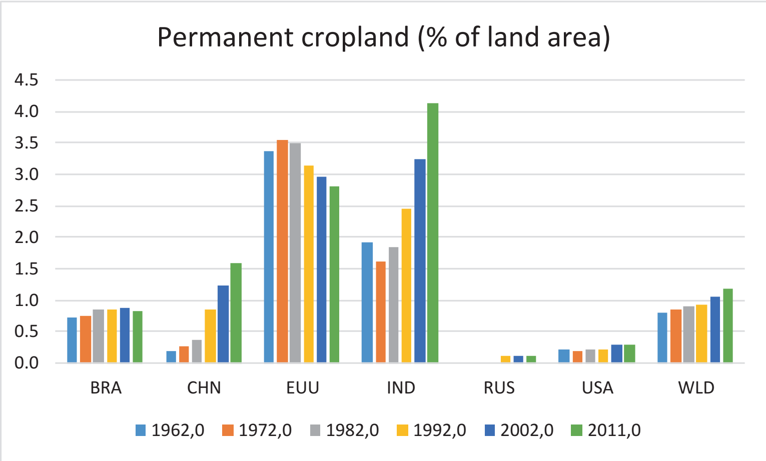

Fig. 4.5 Percentage in some specific countries that is permanent crop land. The countries are Brazil, China, the EU, India, Russia and the USA. Also the world average is given

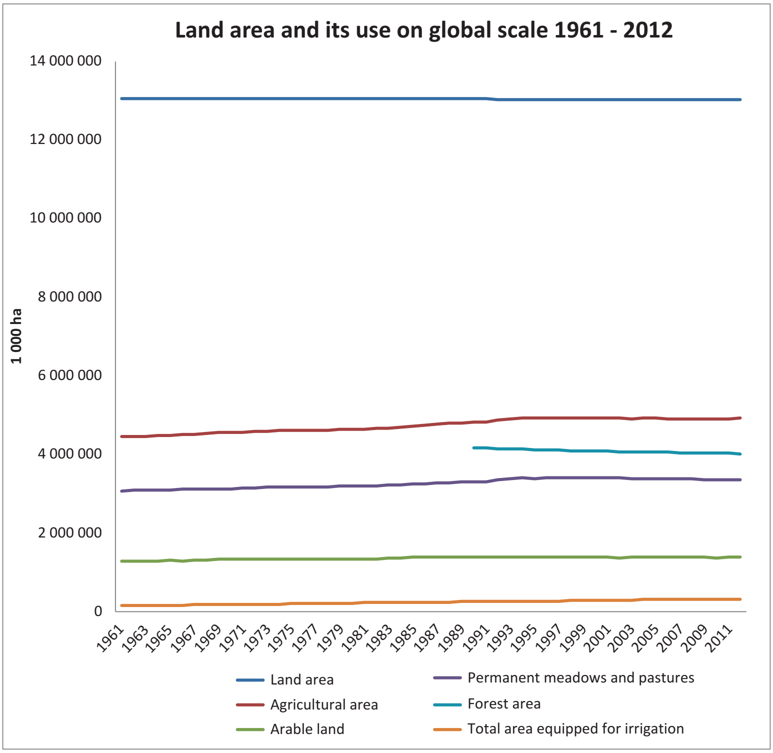

Fig. 4.6 Global area of land in total; in the categories agricultural land, with the sub-categories arable land, permanent meadows and pastures, area equipped for irrigation and forests (Data from FAOstat, 2016-06-23)

pasture, land under market and kitchen gardens and land temporarily fallow (less than 5 years). The abandoned land resulting from shifting cultivation is not included in this category.

A cultivated permanent meadow & pasture is the land under permanent meadows and pastures that is managed and cultivated. A period of more than 5years is used to differentiate between temporary and permanent meadows.

Naturally grown permanent meadows and pastures is the land not controlled under permanent meadows and pastures such as wild prairie or grazing land.

These definitions are important. Often there are confusions in the way these categories are used, also in scientific contexts.

Figure 4.7 shows the share of total area of land for different land-uses globally. From 1990 to 2012 the share of forest land decreased, and agricultural land increased. Table 4.1 shows the actual shares in 1990, 2000 and 2012.

In 2012, agricultural land was 37.8% of total land area, an increase from 0.370 in 1990. However, from 2000 its share had decreased some. The share of arable land was quite constant from 1990 to 2000, to 2012, with a share in 2012 of 0.107. From 1990 to 2000 the share of permanent meadows and pastures increased from 0.253 to

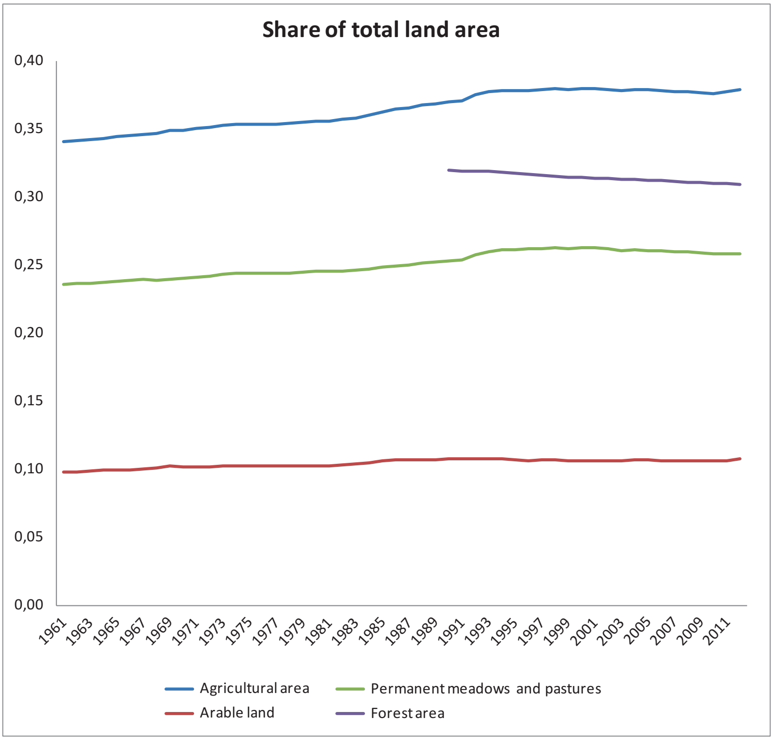

Fig. 4.7 Share of total land area for agricultural land, arable land, permanent meadows and pastures and forests globally (Data, see Fig. 4.1)

Table 4.1 Share of total land area globally for the land-uses agricultural land, arable land, permanent meadows and pastures and forests

	1990	2000	2012
Land area, million ha	13 055	13 012	13 009
Agricultural area	0.370	0.379	0.378
Arable land	0.107	0.106	0.107
Permanent meadows and pastures	0.253	0.263	0.258
Forest area	0.319	0.314	0.309

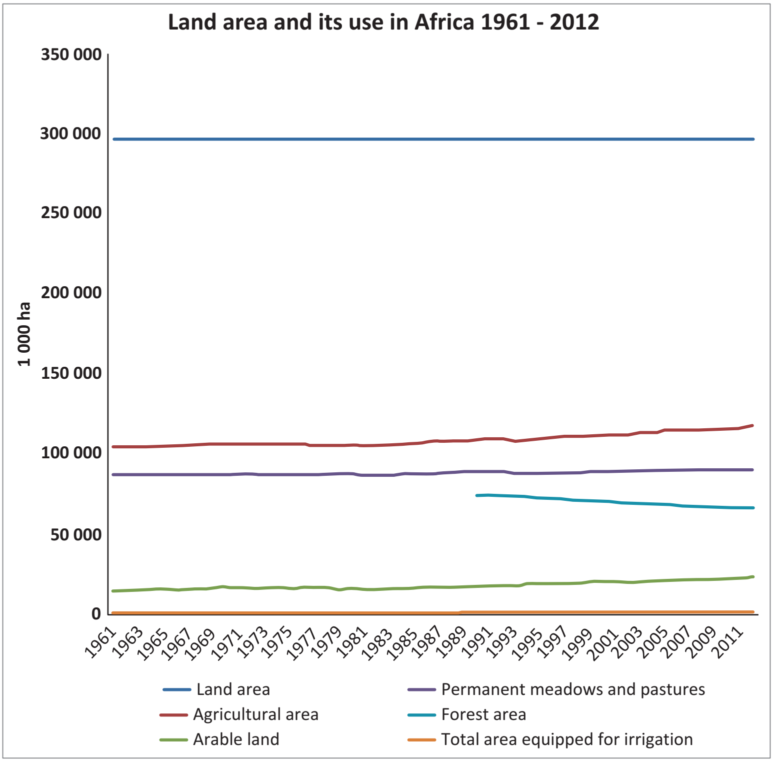

Fig. 4.8 Area of land in Africa in total; in the categories agricultural land, with the sub-categories arable land, permanent meadows and pastures, area equipped for irrigation and forests (Data from FAOstat, 2016-06-23)

0.263. Half of the increase in 2000 was gone in 2012, giving a share of 0.258. Forestry land decreased from 0.319 in 1990 to 0.309 in 2012.

In total, the share of agricultural land and forests on the global scale was 0.687 of total land area.

The few following figures and tables show land use in some major geographic regions. We start with Africa, Fig. 4.8.

Table 4.2 shows the actual shares in 1990, 2000 and 2012.

Table 4.2 Share of total land area in Africa for the land-uses agricultural land, arable land, permanent meadows and pastures and forests

	1990	2000	2012
Land area, million ha	2965	2965	2965
Agricultural area	0.369	0.379	0.397
Arable land	0.061	0.068	0.080
Permanent meadows and pastures	0.300	0.301	0.305
Forest area	0.253	0.239	0.225

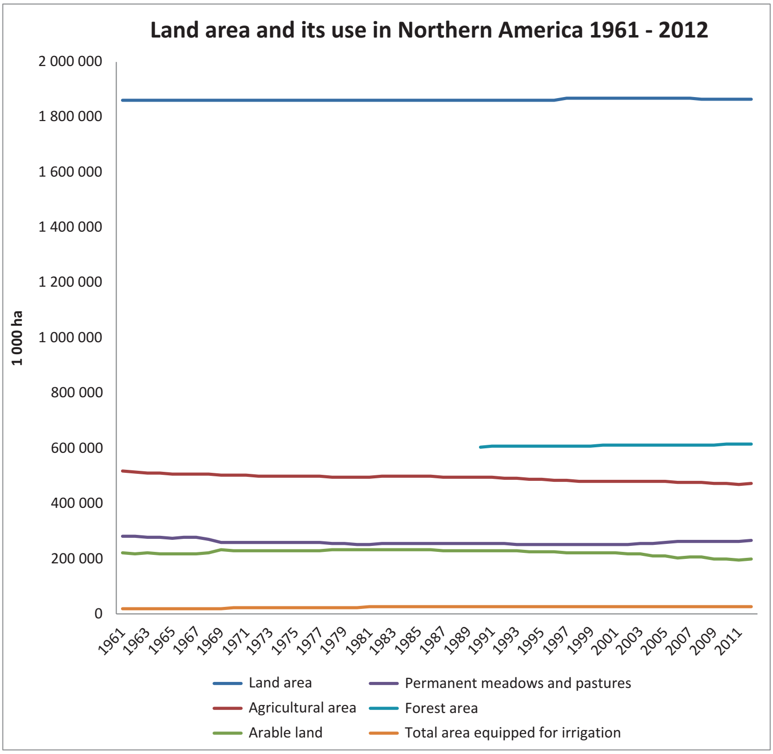

Fig. 4.9 Area of land in North America in total; in the categories agricultural land, with the sub-categories arable land, permanent meadows and pastures, area equipped for irrigation and forests (Data from FAOstat, 2016-06-23)

From 1990 to 2012 the share of agricultural land increased from 0.369 to 0.397, arable land increased from 0.061 to 0.080, and permanent pastures and meadows from 0.300 to 0.305. Forest areas decreased from 0.253 to 0.225, i.e. a decrease of 11%.

Compared with global figures, the share of agricultural land is similar, within agricultural land the share of arable land is lower while permanent pastures and meadows appropriate a higher fraction of total land. In 2012, the fraction of forest land of total in Africa was 0.225 while on the global level it was 0.309.

Figure 4.9 shows the land-use in North America.

Table 4.3 shows the actual shares in 1990, 2000 and 2012.

Table 4.3 Share of total land area in Northern America for the land-uses agricultural land, arable land, permanent meadows and pastures and forests

	1990	2000	2012
Land area, million ha	1859	1867	1865
Agricultural area	0.266	0.258	0.254
Arable land	0.124	0.118	0.108
Permanent meadows and pastures	0.137	0.135	0.143
Forest area	0.326	0.327	0.330

From 1990 to 2012 the share of agricultural land decreased from 0.266 to 0.254, arable land decreased from 0.124 to 0.108, and permanent pastures and meadows increased from 0.137 to 0.143. Forest areas increased from 0.326 to 0.330.

Compared with global figures, the share of agricultural land is substantial lower, explained by a lower fraction of permanent meadows and pastures. Share of forestry area is quite similar to global averages.

Figure 4.10 shows the land-use in South America.

The area of agricultural land increases at the expense of forestry areas.

Table 4.4 shows the actual shares 1990, 2000 and 2012.

From 1990 to 2012 the share of agricultural land increased from 0.316 to 0.351, with an increase for arable land from 0.056 to 0.077, and permanent pastures and meadows from 0.253 to 0.267. Forest areas decreased from 0.541 to 0.491, i.e. a decrease of 9% from the value for 1990.

Compared with global figures, the share of agricultural land is somewhat lower, explained by a lower share of arable land. Share of forestry area is quite similar to global averages. The fraction of forestry areas of total land area was close to 50% in 2012, while the global value was around 30%.

Figure 4.11 shows the land-use in Asia.

Data from FAOstat suggest a substantial increase in the size of Asia from 1991 to 1992. Our interpretation is that there was some impact on official statistics when the Soviet Union collapsed.

Table 4.5 shows the actual shares in 1992, 2000 and 2012.

Note, here data is provided for the year 1992 instead of 1990 as for the other regions. The reason is to eliminate the hack in the curves in Fig. 4.11 between 1991 and 1992.

From 1992 to 2012 the share of agricultural land increased from 0.516 to 0.526, with a decrease for arable land from 0.162 to 0.150, while permanent pastures and meadows increased from 0.337 to 0.348. Forest areas increased from 0.185 to 0.195.

Compared with global figures, the share of agricultural land is substantially higher, with a share of total land of 0.526 in 2012, while the global share was 0.378. The shares of arable land and permanent meadows and pastures are higher than on the global scale. Forestry areas are slightly lower than 20% while the global value is slightly more than 30%.

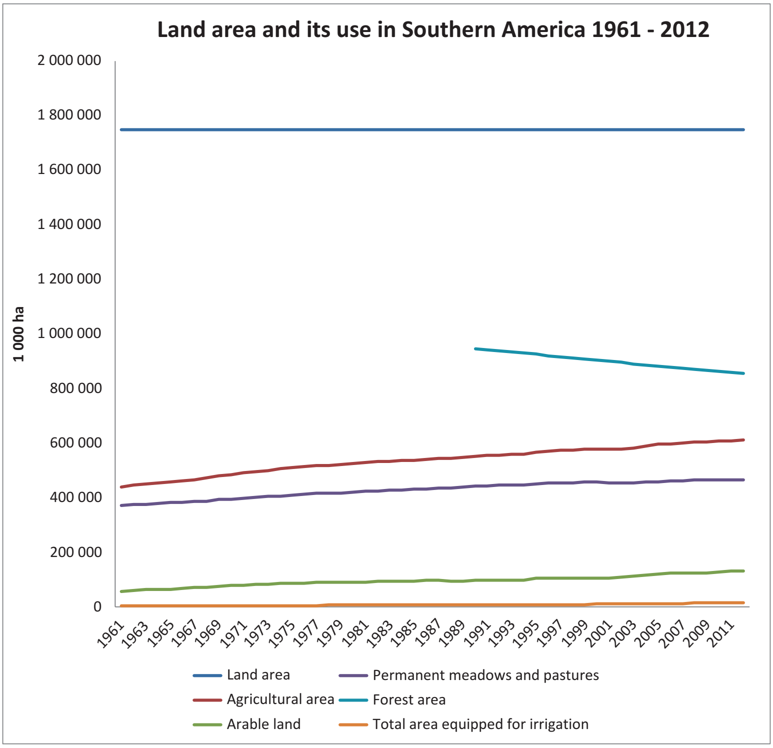

Fig. 4.10 Area of land in South America in total; in the categories agricultural land, with the sub-categories arable land, permanent meadows and pastures, area equipped for irrigation and forests (Data from FAOstat, 2016-06-23)

Table 4.4 Share of total land area in South America for the land-uses agricultural land, arable land, permanent meadows and pastures and forests

	1990	2000	2012
Land area, million ha	1749	1746	1746
Agricultural area	0.316	0.331	0.351
Arable land	0.056	0.061	0.077
Permanent meadows and pastures	0.253	0.262	0.267
Forest area	0.541	0.518	0.491

Figure 4.12 shows the land-use in Europe.

Data from FAOstat suggest a substantial decrease in the size of Europe from 1991 to 1992. Our interpretation is that there was some impact on official statistics when the Soviet Union collapsed.

Table 4.6 shows the actual shares in 1992, 2000 and 2012.

Note, here data is provided for the year 1992 instead of 1990 for the other regions. The reason is to eliminate the hack in the curves in Fig. 4.12 between 1991 and 1992.

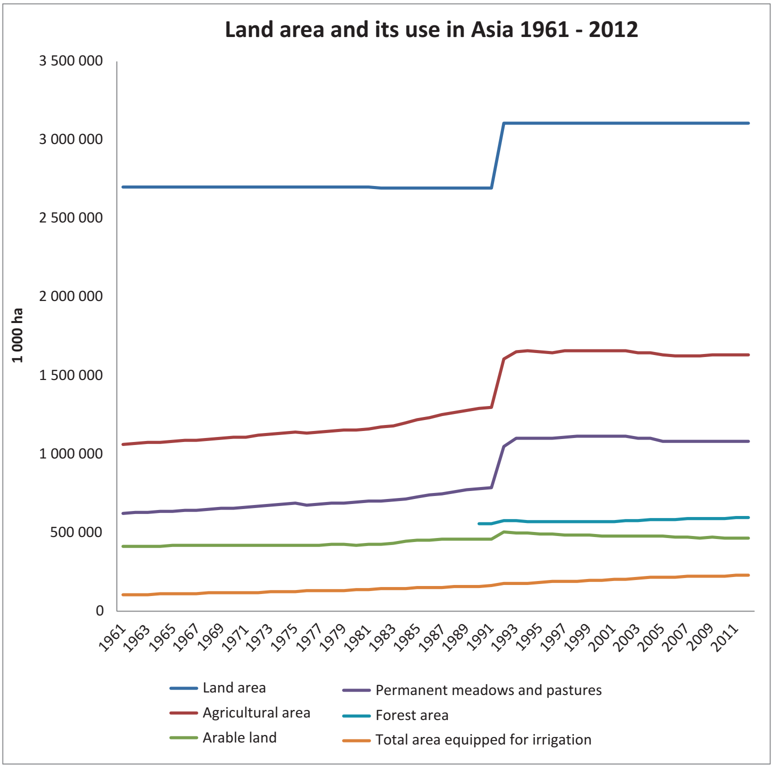

Fig. 4.11 Area of land in Asia in total; in the categories agricultural land, with the sub-categories arable land, permanent meadows and pastures, area equipped for irrigation and forests (Data from FAOstat, 2016-06-23)

Table 4.5 Share of total land area in Asia for the land-uses agricultural land, arable land, permanent meadows and pastures and forests

Asia + (Total)	1992	2000	2012
Land area, million ha	3106	3104	3103
Agricultural area	0.516	0.534	0.526
Arable land	0.162	0.155	0.150
Permanent meadows and pastures	0.337	0.360	0.348
Forest area	0.185	0.184	0.192

From 1992 to 2012 the share of agricultural land decreased from 0.225 to 0.211, with a decrease for arable land from 0.136 to 0.124, while the share of permanent pastures and meadows remained constant. Forest areas increased from 0.447 to 0.455.

Compared with global figures, the share of agricultural land is substantially lower, with a share of total land of 0.211 in 2012, while the global share was 0.378. The share of arable land was 0.124 in Europe in 2012, which is somewhat higher than the global value of 0.107. Permanent meadows and pastures appropriated 8% of total land area in Europe in 2012, and 25.8% on the global level.

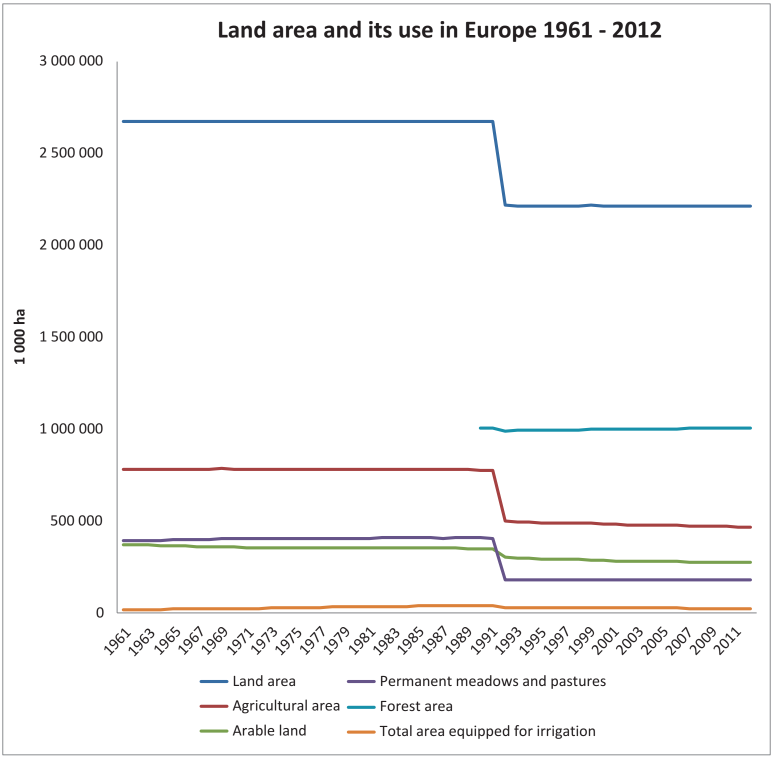

Fig. 4.12 Area of land in Europe in total; in the categories agricultural land, with the sub-categories arable land, permanent meadows and pastures, area equipped for irrigation and forests (Data from FAOstat, 2016-06-23)

Table 4.6 Share of total land area in Europe for the land-uses agricultural land, arable land, permanent meadows and pastures and forests

	1992	2000	2012
Land area, million ha	2215	2214	2213
Agricultural area	0.225	0.219	0.211
Arable land	0.136	0.130	0.124
Permanent meadows and pastures	0.081	0.082	0.080
Forest area	0.447	0.451	0.455

Forestry areas in Europe cover 45.5% of total land and 30.9% globally.

Figure 4.13 shows the land-use in Oceania.

There is quite a decrease in agricultural land from the late 1970s explained by a decrease of permanent meadows and pastures.

Table 4.7 shows the actual shares in 1990, 2000 and 2012.

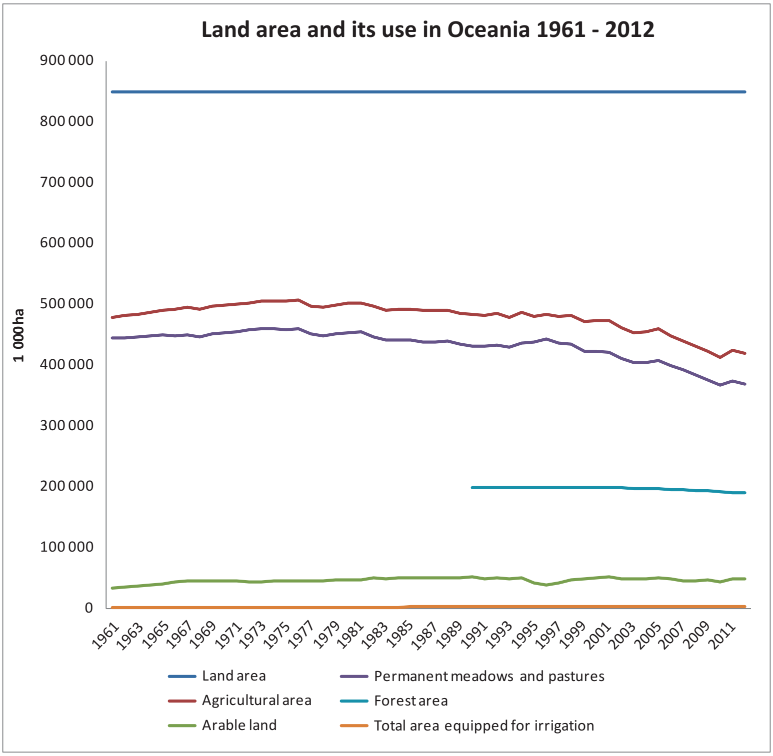

Fig. 4.13 Area of land in Oceania in total; in the categories agricultural land, with the sub-categories arable land, permanent meadows and pastures, area equipped for irrigation and forests (Data from FAOstat, 2016-06-23)

Table 4.7 Share of total land area in Oceania for the land-uses agricultural land, arable land, permanent meadows and pastures and forests

Oceania + (Total)	1990	2000	2012
Land area, million ha	849	849	849
Agricultural area	0.569	0.557	0.494
Arable land	0.060	0.058	0.057
Permanent meadows and pastures	0.507	0.498	0.435
Forest area	0.234	0.234	0.223

From 1990 to 2012 the share of agricultural land decreased from 0.569 to 0.494, mainly explained by a decrease of permanent pastures and meadows from 0.507 to 0.435. Forest areas decreased slightly from 0.234 to 0.223.

Compared with global figures, the share of agricultural land is substantially higher, with a share of total land of 0.494 in 2012, while the global share was 0.378. The share of arable land was 0.057 in Oceania in 2012, slightly more than half the global share. Permanent meadows and pastures appropriated 43.5% of total land area in Oceania in 2012, with 25.8% on the global level.

Forestry areas in Oceania cover 22.3% of total land and 30.9% globally.

In the presentation on regional level, Central America and the Caribbean are omitted. They represent 3% of the global agricultural land 1961–2012.

4.2.2 Summary and Discussion

From 1990 (1992 for Asia and Europe) to 2012

- Agricultural land of total land area
  - Increases
    - On the global level from 37.0 to 37.8%
    - In Africa from 36.9 to 39.7%
    - In South America from 31.6 to 35.1%
    - In Asia from 51.6 to 52.6%
  - Decreases
    - In Northern America from 26.6 to 25.4%
    - In Europe from 22.5 to 21.1%
    - In Oceania from 56.9 to 49.4%
- Of agricultural land
  - Arable land as a share of total land area
    - Increases in
      - Africa from 6.1 to 8.0%
      - South America from 5.6 to 7.7%
    - Decreases in
      - Northern America from 12.4 to 10.8%
      - Asia from 16.2 to 15.0%
      - Europe from 13.6 to 12.4%
      - Oceania from 6.0 to 5.7%
    - Remains stable at the share 10.7% globally
  - Permanent meadows and pastures
    - Increases
      - Globally from 25.3 to 25.8%
      - In Africa from 30.0 to 30.5%
      - In Northern America from 13.7 to 14.3%
      - In South America from 25.3 to 26.7%
      - In Asia from 33.7 to 34.8%

    - Decreases
        - Slightly in Europe from 8.1 to 8.0%
        - In Oceania from 50.7 to 43.5%.

- Forest area
    - Increases
        - In Northern America from 32.6 to 33.0%
        - Asia from 18.5 to 19.2%
        - Europe from 44.7 to 45.5%
    - Decreases
        - Globally from 31.9 to 30.9%
        - In Africa from 25.3 to 22.5%
        - In South America from 54.1 to 49.1%
        - Oceania from 23.4 to 22.3%

In South America, the loss of forests this period is 5.0%-units of total land area, while the increase in agricultural land is 3.5%-units. Arable land increases with 2.1% units and permanent meadows and pastures with 1.4%-units. Thus, 1.5%-units of the loss of forestry areas are not explained by transformation to agricultural land. Arable land mainly produces food and feed to monogastric animals such as poultry, pigs and people. Permanent meadows mainly produce feeds to ruminants such as cattle, sheep and goats. Also, species within the horse family and camelids have the capacity to utilise feeds from permanent meadows and pastures and from shrubs rich in cellulose and other fibres.[1] The figures for South America suggest that here the growth of poultry and pig production is a stronger driver for deforestation than ranching. The increase in agricultural land is 61 million ha. Of this, 37 million ha is as arable land, and 24 as permanent meadows and pastures. From 1990 to 2012 the area of soybean production in South America increased by 30.0 million ha.[2]

Europe and South America have the highest share of forestry land, between 45 and 50%. The decrease in South Africa to 70% is explained by a transformation to agricultural land. One spectrum of ecosystem service production typical for forests is transformed to another typical for agricultural land. This has both costs and benefits for human wellbeing in the short and long run.

The increase in area for soybean production suggests that the deforestation is to a significant part driven by an increase in pig and poultry production, not cattle production.

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[1] These categories of animals have the capacity to through "cooperation" with microbes within the digestive tract break the chemical bounds of glucose constituting cellulose, while monogastrics such as poultry, pigs and people cannot. This explains why ruminants offer a way to produce food for people from sunlight in the otherwise marginal agroecosystems that now are used as permanent meadows and pastures. This is the reason for their success as wild and as farm animals.

[2] Data from FAOtstat, http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor, accessed 2016-06-26.

In the presentation on regional level, Central America and the Caribbean are omitted. They represent 3% of global agricultural land 1961–2012.

4.3 Some Inputs to Agriculture

4.3.1 Use of Fertilisers

The global consumption of nitrogen in commercial fertilisers increased from 86 million tonnes in 2002 to 120 in 2012. During the same period, the use of phosphorus increased from 34 to 46 million tonnes (measured as P_2O_5), and the use of potash from 24 to 28 million tonnes (measured as K_2O) (Fig. 4.14).

Figure 4.15 presents the application rate of nitrogen fertilisers per ha arable land globally, and for some major regions.

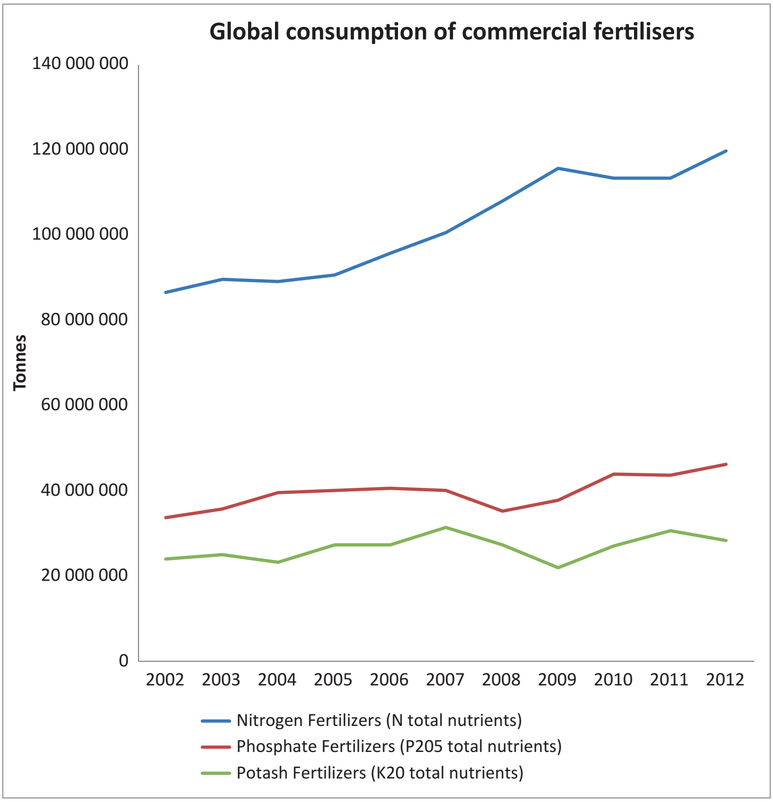

Fig. 4.14 Global consumption of commercial fertilisers 2002–2012 in tonnes (Data from FAOstat, accessed 2016-06-25)

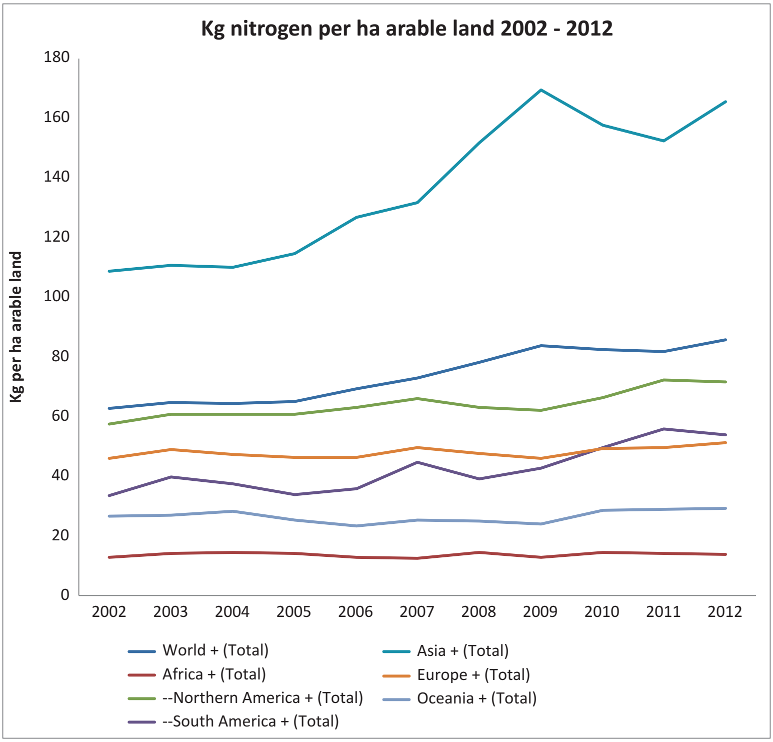

Fig. 4.15 Application of nitrogen in kg per ha arable land globally, and for some major regions, 2002–2012 (Data from FAOstat accessed 2016-06-25)

The average amount of nitrogen from commercial fertilisers per ha arable land in 2012 in Asia was 166 kg, globally 86 kg, in North America it was 72 kg. The application in South America corresponded to 54 kg, in Europe to 51 kg, in Oceania to 30 kg and in Africa to 14 kg.

Figure 4.16 presents the application of phosphorus as kg P_2O_5, per ha arable land globally, and for some major regions.

The average amount of P_2O_5 from commercial fertilisers per ha arable land in 2012 in Asia was 62 kg, in South America 43 kg, globally 33 kg, in Oceania 28 kg, in North America 23 kg, in Europe 13 kg and Africa 6 kg.

4.3.2 Use of Biocides

The name biocides can sound quite harmless; its connotation is something that kills life, bios. Three major types are insecticides, herbicides and fungicides/bactericides. Their purpose is to kill insects, weeds, fungi and bacteria.

Figure 4.17 shows global uses of biocides.

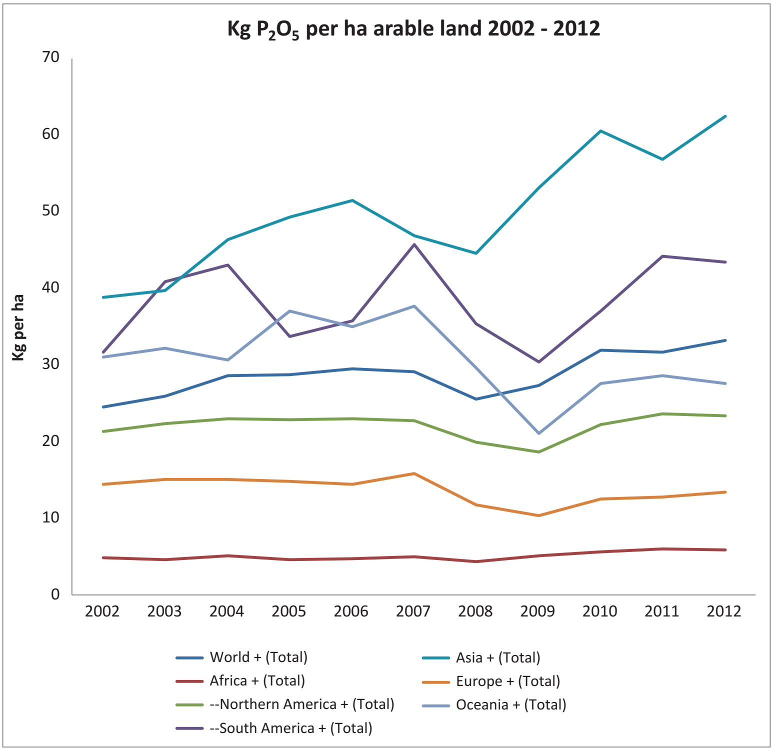

Fig. 4.16 Application of phosphorus in kg P_2O_5 per ha arable land globally, and for some major regions, 2002–2012 (Data from FAOstat accessed 2016-06-25)

The advantage of biocides is that they can improve yields as competing organisms are controlled. The disadvantage is that they can cause negative impacts on other organisms such as predators on parasites, pollinating insects and humans.

The sharp drop in use after 2007 is noteworthy.

By using plant growth regulators, problems with straw growth that complicates the harvest are decreased.

4.4 Production of Food

4.4.1 Overview

The major purpose of agriculture is to produce food for humans. Through the invention of agriculture humans increased the carrying capacity of the planet with regard to humans by a factor of 100–1000 (Hellstrand et al. 2009; see also Pimentel and Pimentel 2008). The two major routes are through production of edible crops and through plants that result in animal products humans can consume. We start with crop production here.

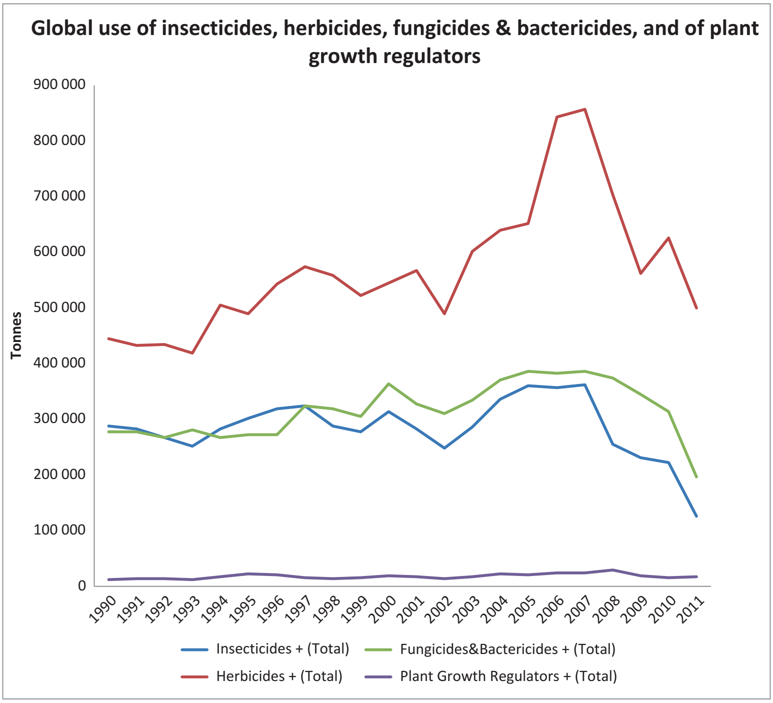

Fig. 4.17 Global uses of biocides; insecticides, herbicides, fungicides/bactericides in tonnes. Also the amount of plant growth regulators is shown (Data from FAOstat, accessed 2016-06-25)

Figure 4.18 gives the dominating categories of crops on arable land measured as areas for production.

In 2012, the area harvested for cereals was 705 million ha, for oilcrops 281 million ha, for pulses 80 million ha, for vegetables 57 million ha, for fruits excl melons 57 million ha, and for roots and tubers 56 million ha. The area for oil crops increased by a factor of 2.5 from 1961 (Table 4.8).

The area of cereals is quite stable, oilcrops have more than doubled from 1961 to 2012, fruits and vegetables have doubled. Cereals dominated both in 1961 and 2012.

Figure 4.19 gives the production in million tonnes of major crop categories.

The blue curve for total production of cereals is a beautiful curve. It is a major explanation for the increase in life-length and population that we have globally experienced since 1961 to recent years. When comparing production quantities it should be remembered that typically cereals have a dry matter content close to 90% while, e.g. roots and tubers have a dry matter content around 20%. It is the produced amount of energy and protein corrected for its biological value for humans that should be compared.

Table 4.9 presents the global production in million tonnes for some major crop categories in 1961, 1986, and 2012.

The production of cereals increased by a factor of 2.9 from 1961 to 2012.

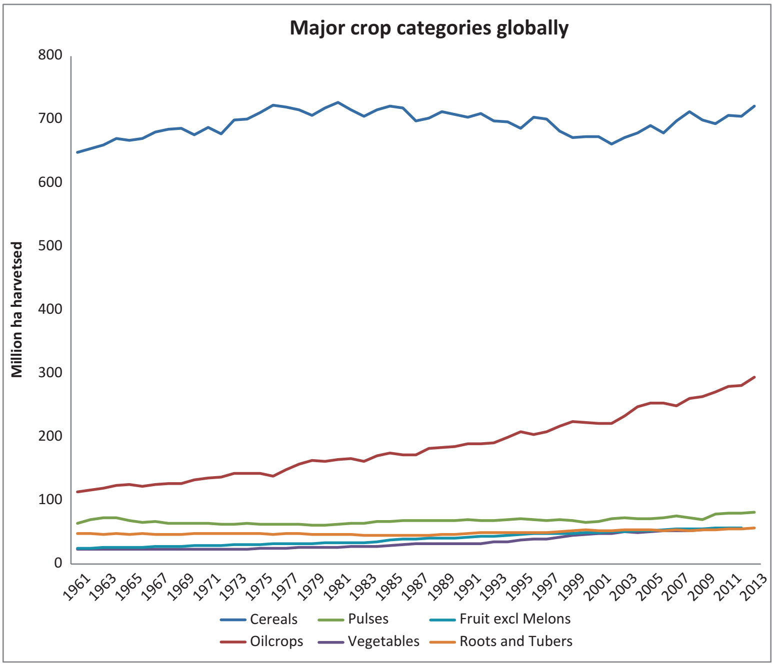

Fig. 4.18 Major crops categories globally, million ha harvested 1961–2013 (Data from FAOstat, accessed 2016-06-26)

Table 4.8 Global areas harvested for some major crop categories in 1961, 1986 and 2012 (Data from FAOstat accessed 2016-06-26)

	Harvested areas million ha		
	1961	1986	2012
Cereals	648	717	705
Oilcrops	114	172	281
Pulses	64	69	80
Vegetables	24	30	57
Fruit excl melons	25	39	57
Roots and tubers	48	45	56
Fibre crops	39	37	38
Treenuts	2	4	10
Citrus fruit	2	5	9
Jute & jute-like fibres	3	3	2

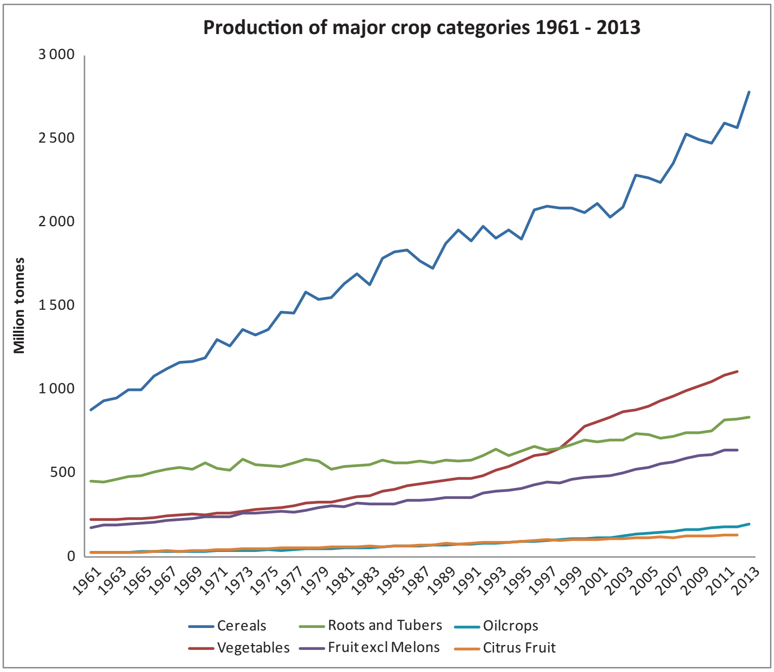

Fig. 4.19 Major crops categories globally, production in million tonnes 1961–2013 (Data from FAOstat, accessed 2016-06-26)

Table 4.9 Global production in million tonnes for some major crop categories in 1961, 1986, and 2012 (Data from FAOstat accessed 2016-06-26)

	Production million tonnes		
	1961	1986	2012
Cereals	877	1834	2566
Vegetables	223	427	1106
Roots and tubers	455	564	822
Fruit excl melons	175	338	637
Oilcrops	26	64	181
Citrus fruit	25	67	131
Pulses	41	52	73
Fibre crops	15	22	31
Treenuts	3	4	14
Jute & jute-like fibres	3	4	4

4.4.2 *Productivity in Cereal Production Related to Land and Fertilisers*

The issue of the productivity in relation to appropriated natural capital and natural resources is crucial in a sustainable development.

The major natural resource appropriated in agriculture is agricultural land, which can be divided into the main categories arable land and permanent meadows and pastures.

Arable land mainly produces food for humans, but to some degree also feeds mainly for poultry and pigs. Permanent meadows and pastures mainly produce pasture and forages fed ruminants, producing food for people. We will return to that path later.

Here, we focus on the productivity of arable land.

Figure 4.20 presents the productivity in 1961–2013 in cereal production compared to the appropriation of the natural capital arable land, i.e. the yields.

In North America the productivity increased from around 2200 kg per ha a year to somewhere between 6000 and 7000 kg per ha. On the global level, Fig. 4.15 suggests the yield increased from less than 1500 kg to around 3500 kg per ha. Africa still is at the bottom, however, here the yields have also increased substantially, from less than 1000 kg per ha to around 1500.

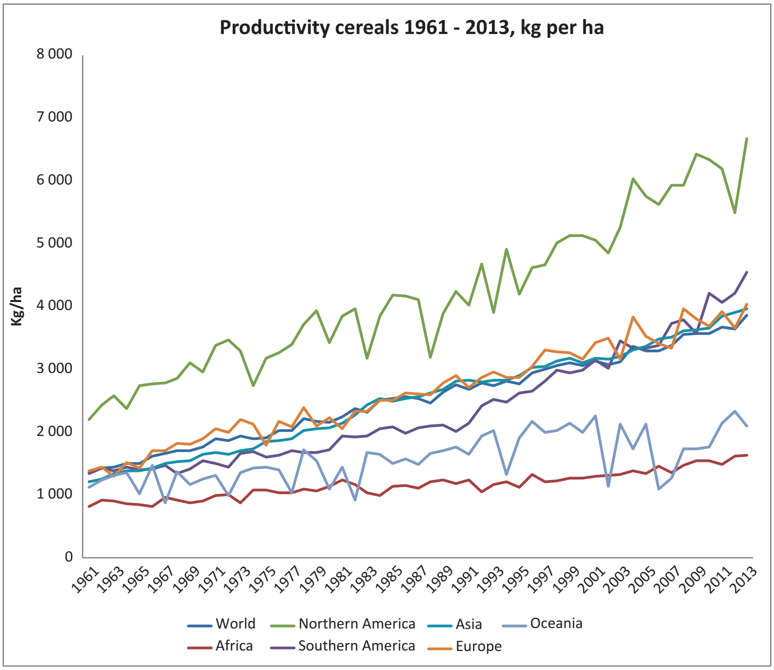

Fig. 4.20 The productivity in 1961–2013 in cereal production compared to the appropriation of the natural capital arable land, i.e. the yields (Data from FAOstats, accessed 2016-06-25)

Table 4.10 Productivity in appropriation of arable land in cereal production in 1961, 1987 and 2013 globally and for some major regions

	1961	1987	2013	2013/1961
World	1353	2540	3861	2.85
Africa	810	1112	1628	2.01
North America	2203	4112	6671	3.03
South America	1347	2072	4550	3.38
Asia	1212	2565	3956	3.26
Europe	1379	2605	4033	2.92
Oceania	1115	1484	2095	1.88

Data source, see Fig. 4.20

Table 4.10 gives the accurate numbers.

As we can see, there are quite impressive increases in yields, i.e. the productivity in land used for cereal production from 1961 to 2013, on the global scale, and in each one of the regions in Table 4.11.

Figure 4.21 gives the productivity in 1961–2013 in the appropriation of arable land for production of protein feeds measured as oil cake equivalent.

Table 4.11 gives the productivity figures for 1961, 1987 and 2013.

The curve for South America (Fig. 4.21) and values for 1961, 1987 and 2013 (Table 4.11) are astonishing.

Roots and tubers are important foods in traditional cooking in many regions. Thus, their production can have a substantial importance for local and regional food security.

Figure 4.22 gives the productivity in 1961–2013 in the appropriation of arable land for production of roots and tubers.

Table 4.12 presents the productivity figures for 1961, 1987 and 2013.

The values for North America suggest that most regions can reach a substantially higher production level, and that the potential for improvements is high.

Figure 4.23 shows the productivity in cereal production globally and for some major regions in relation to the input of nitrogen fertilisers.

From 2002 to 2012 the productivity in terms of amount of cereal production per kg nitrogen fertiliser used increased from 63 to 86 kg, i.e. an increased productivity of 37%. However, there is a need to be somewhat cautious in the interpretation. Here, it is assumed that all nitrogen fertilisers in global agriculture are used in cereal production. Cereal production is the dominating production, but some fertilisers are used in other production as well.

Figure 4.24 presents the productivity in 2002–2012 in cereal production with phosphorus fertilisers.

The results on the global and regional level are quite interesting. Below, the main results are summarised in tables showing the development in cereal production in relation to land productivity, nitrogen productivity and phosphorus productivity. First, we present Tables 4.13, 4.14 and 4.15, then we comment on their major results.

Table 4.11 Productivity in appropriation of arable land in production of protein feeds measured as kg oil cake equivalent produced per ha globally and for some major regions in 1961, 1987 and 2013

	1961	1987	2013	2013/1961
World	430	832	1220	2.84
Africa	237	278	358	1.51
North America	918	1517	1946	2.12
South America	357	1143	2046	5.73
Asia	296	550	756	2.56
Europe	477	905	1166	2.45
Oceania	316	523	809	2.56

Data source, see Fig. 4.21

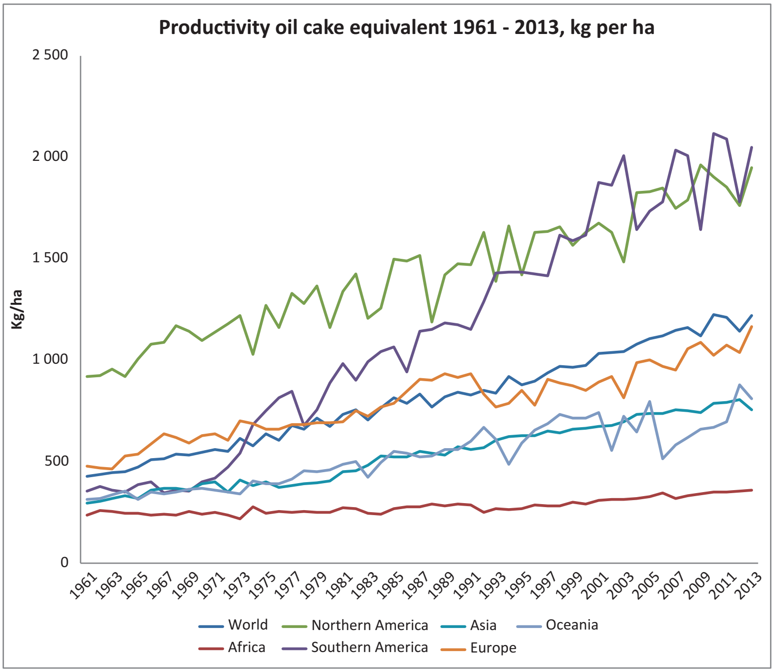

Fig. 4.21 The productivity in 1961–2013 in the appropriation of arable land for production of protein feeds measured as oil cake equivalent (Data from FAOstats, accessed 2016-06-25)

Here, P_2O_5 was transformed to P, using the figure 0.436, the share of phosphorus in P_2O_5.

In terms of land-productivity, Africa lags behind development of other regions and on the global level (Table 4.13). Still, the production per ha has doubled. Africa is now at a level where the other regions started a substantial increase; South America increased from 1347 to 4550 kg per ha from 1961 to 2013, North America

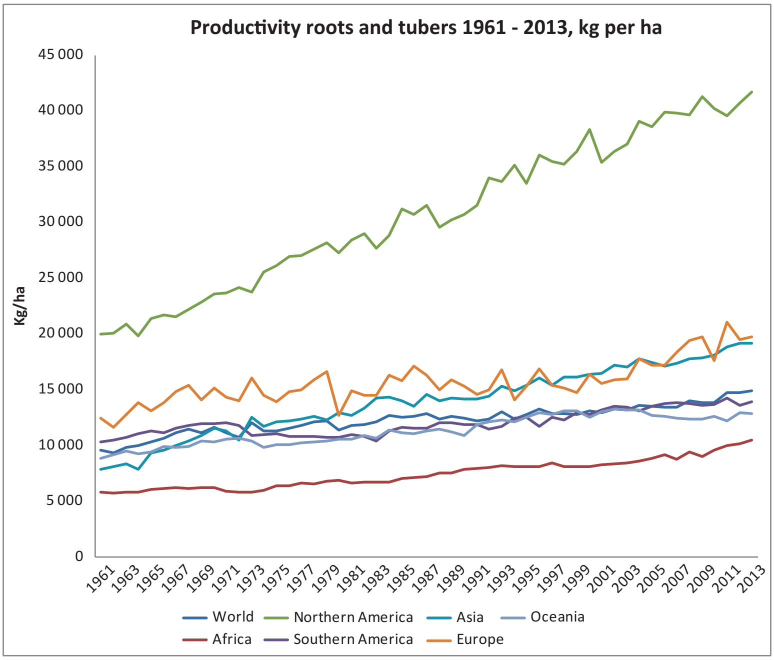

Fig. 4.22 The productivity in 1961–2013 in the appropriation of arable land for production of roots and tubers (Data from FAOstats, accessed 2016-06-25)

Table 4.12 Productivity in appropriation of arable land in production of roots and tubers globally and for some major regions in 1961, 1987 and 2013

	1961	1987	2013	2013/1961
World	9568	12 838	14 895	1.56
Africa	5779	7185	10 484	1.81
North America	20 002	31 509	41 688	2.08
South America	10 331	11 551	13 954	1.35
Asia	7860	14 585	19 173	2.44
Europe	12 488	16 304	19 726	1.58
Oceania	8839	11 276	12 856	1.45

from 2203 to 6671, Asia from 1212 to 3956 and global production increased from 1353 to 3861 kg per ha. Oceania is between Africa and the other regions with an increase from 1115 to 2095 kg per ha.

When looking at the productivity in relation to nitrogen fertiliser, the picture is altered. Now, Africa is without competition best in the class, with a production of cereals that increased from 103 to 117 kg cereals per kg nitrogen in commercial

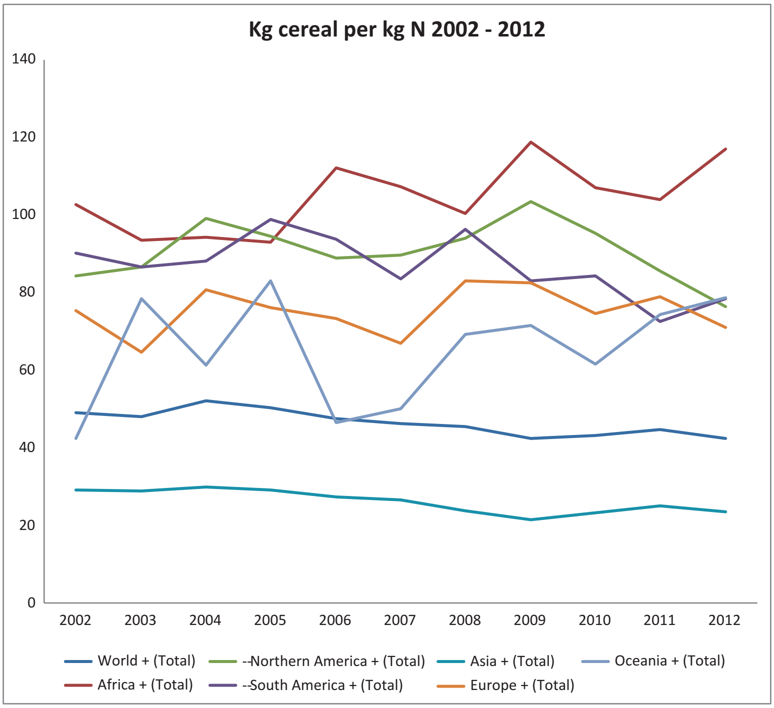

Fig. 4.23 The productivity in cereal production globally from 2002 to 2012 measured as kg cereal yield per kg nitrogen used (Data from FAOstat, accessed 2016-06-25)

fertilisers. Oceania in 2012 was second at 79 kg cereals per kg N, with South America, North America and Europe close behind. Asia has the lowest nitrogen productivity with 24 kg cereals per kg nitrogen.

The first question is if there are hidden factors distorting the results. If not, this is a signal that there are areas to work with to improve the economy in the production system, and decrease nutrient run-off that may harm the environment and human health. From 2002 to 2012, the nitrogen productivity decreased in South America and North America as well, while Oceania has close to doubled it.

Africa also leads the race regarding phosphorus productivity. In 2012, their production of cereals was 618 kg per kg P applied, North America reached 601 kg, Europe 580 kg, South America 177 kg, Asia 163 kg and Oceania 130 kg.

On the farm level, one of the major challenges is to divert limited resources to the production units—animals or fields—which on the margin gives the highest marginal return. This implies that resources that are used in an inefficient way are removed from those animals and those fields that are not doing a proper job, and provided to those animals and fields that by these extra resources increases overall farm/system performance.

Another challenge is to give the right amount of feed, or fertilisers, so that on the margin it gives a net contribution compared to all other possible ways of using it.

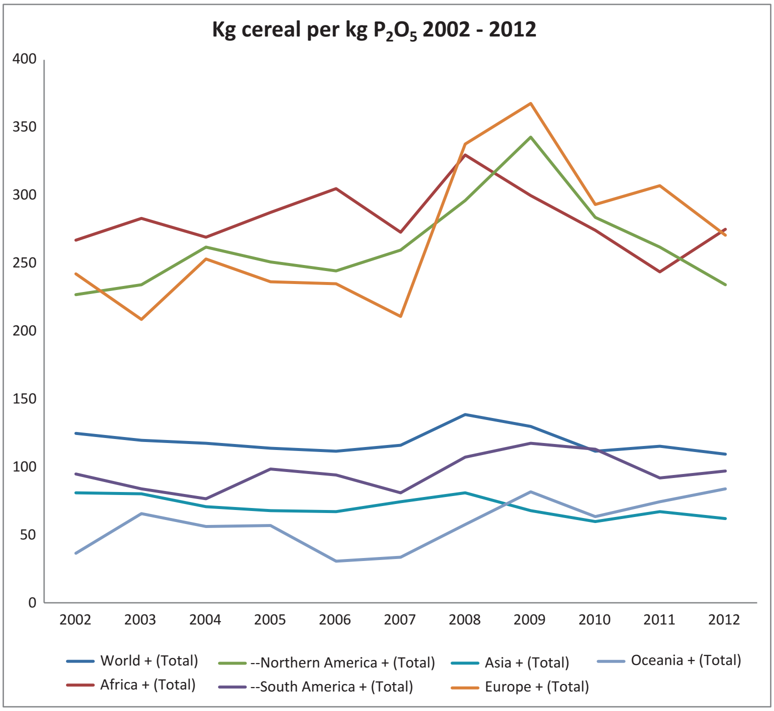

Fig. 4.24 The productivity in cereal production globally in 2002–2012 measured as kg cereal yield per kg P_2O_5 used (Data from FAOstat, accessed 2016-06-25)

Table 4.13 Land-productivity: kg cereal per ha

	1961	1987	2013
World	1353	2540	3861
Africa	810	1112	1628
North America	2203	4112	6671
South America	1347	2072	4550
Asia	1212	2565	3956
Europe	1379	2605	4033
Oceania	1115	1484	2095

Table 4.14 Nitrogen productivity: kg cereal per kg N fertiliser

	2002	2007	2012
World	49	46	42
Africa	103	107	117
North America	84	90	76
South America	90	83	78
Asia	29	27	24
Europe	75	67	71
Oceania	42	50	79

Table 4.15 Phosphorus productivity: kg cereal per kg P fertiliser

	2002	2007	2012
World	287	276	270
Africa	612	649	618
North America	520	538	601
South America	218	194	177
Asia	187	185	163
Europe	555	479	580
Oceania	84	151	130

Tables 4.13, 4.14 and 4.15 suggest that by looking at the global agricultural system as one gigantic farm, much can be improved by a redistribution of resources such as fertilisers from other regions to Africa. This can improve global food security, decrease environmental pollution, and decrease social stress due to lack of food.

4.4.3 Animal Production

In this section some information regarding animal production with levels and trends is presented. The information is given on the global level and for major geographic areas.

Figure 4.25 gives milk production in 1961–2012 on the global level and for major geographic regions.

Asia drives an increasing global milk production, since 1990 the production in Europe has decreased.

Table 4.16 presents the production volumes in 1980, 2012 and the change during the period on the global level and for major geographic regions.

Global increase in production was 288 million tonnes, in Asia the production increased by 210 million tonnes, i.e. with a factor of 4.0. From a low level the production in Africa increased 2.7 times. In Europe the production dropped by 19%.

Figure 4.26 shows the production per cow at the same time period and geographical areas.

North America has the highest producing cows. From 1961 to 2012 their production increased from a little more than 3000 kg to close to 10 000 kg per year. The differences between regions imply major potentials for increased productivity per animal. The so far unbroken increase in productivity in milk production per cow in North America suggests that they also have potential to utilise increased productivity.

Figure 4.27 presents meat production from 1961 to 2012 on the global level and for major geographic regions.

Asia also drives an increasing global meat production.

Table 4.17 presents the production volumes in 1980, 2012 and the change during the period on the global level and for major geographic regions.

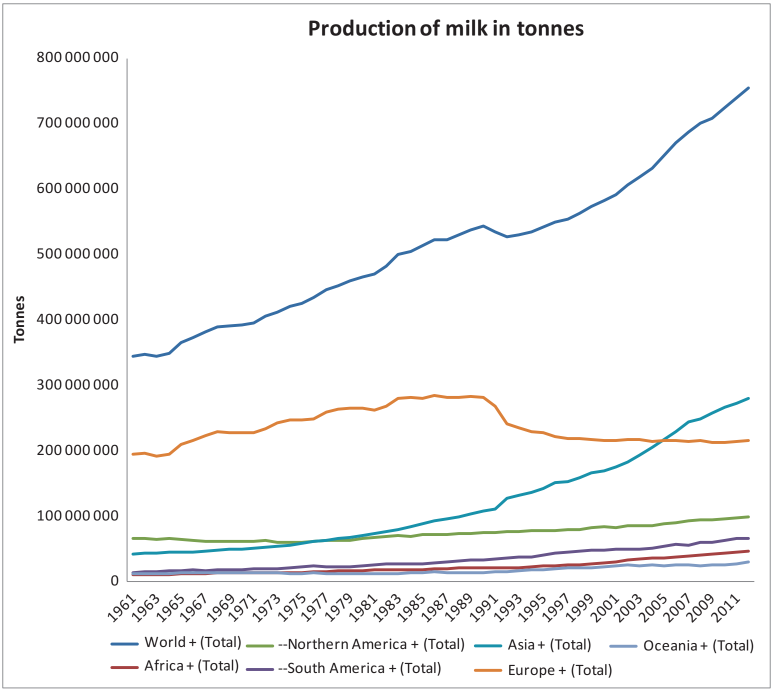

Fig. 4.25 Milk production in tonnes for 1961 to 2012 on the global level and for major geographic regions (FAOstat, accessed 2016-06-27)

Table 4.16 Production volumes for milk in tonnes 1980, 2012 and the change during the period on the global level and for major geographic regions

	1980	2012	2012–1980
World + (Total)	465 819 160	753 925 417	288 106 257
Africa + (Total)	17 084 530	46 192 109	29 107 579
North America + (Total)	65 657 870	99 316 465	33 658 595
South America + (Total)	24 845 476	66 443 204	41 597 728
Asia + (Total)	69 887 995	279 666 027	209 778 032
Europe + (Total)	265 482 850	216 089 386	−49 393 464
Oceania + (Total)	12 330 080	29 603 834	17 273 754

Data from FAOstat accessed 2016-06-27

The global increase in production was 165 million tonnes, in Asia the production increased by 98 million tonnes, i.e. with a factor of 4.4. From a low level the production in Africa increased 2.5 times. In Europe, the production dropped around 1990, and has since recovered to the same level as 1980.

Figure 4.28 gives the global production of different meat categories.

Global production of pig meat increased at the same rate over the period; poultry meat shows an ongoing increase and in 2012 is close to the global production of pig

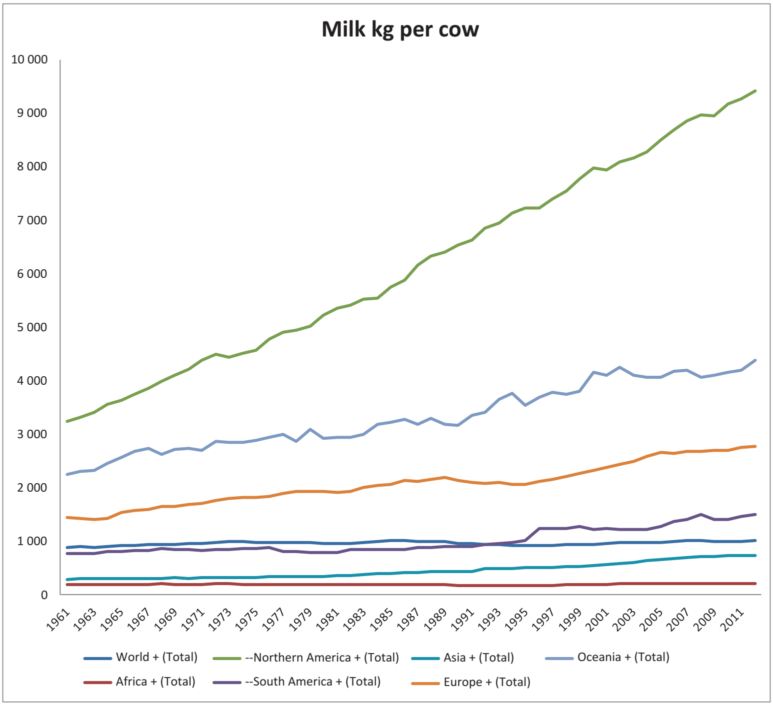

Fig. 4.26 Milk production per cow from 1961 to 2012 on the global level and for major geographic regions (FAOstat, accessed 2016-06-27)

meat. Beef and buffalo meat starts with a slightly higher production in the beginning of the period than pig meat, and shows a slowing increase from around 1975, with a close to stable production from around 2005 onwards.

Figure 4.29 presents production of pig meat from 1961 to 2012 on the global level and for major geographic regions.

Asia dominates an increasing global pig meat production.

Table 4.18 presents the production volumes for 1980, 2012 and the change during the period on the global level and for major geographic regions.

The global increase in production was 56 million tonnes, in Asia the production increased by 45 million tonnes, i.e. with a factor of 2.8. The level of production in Africa increased 3.5 times. In Oceania the production dropped 68%.

Figure 4.30 presents production of poultry meat from 1961 to 2012 on the global level and for major geographic regions.

Asia dominates the globally increasing poultry meat production.

Table 4.19 presents the production volumes for 1980, 2012 and the change during the period on the global level and for major geographic regions.

The global increase in production was 80 million tonnes, in Asia the production increased by 38 million tonnes, i.e. with a factor. The production in Africa increased 4.7 times.

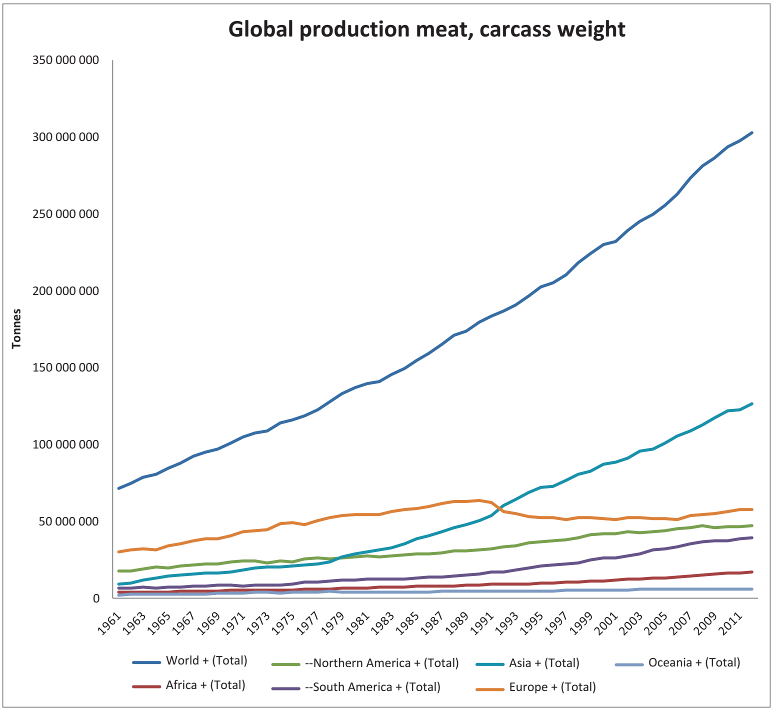

Fig. 4.27 Meat production in tonnes from 1961 to 2012 on the global level and for major geographic regions (FAOstat, accessed 2016-06-27)

Table 4.17 Production volumes for meat in tonnes for 1980, 2012 and the change during the period on the global level and for major geographic regions

	1980	2012	2012–1980
World + (Total)	136 736 369	302 390 507	165 654 138
Africa + (Total)	6 690 227	16 901 905	10 211 678
North America + (Total)	27 012 485	47 032 173	20 019 688
South America + (Total)	12 153 924	39 435 044	27 281 120
Asia + (Total)	28 631 238	126 301 506	97 670 268
Europe + (Total)	54 538 084	57 943 376	3 405 292
Oceania + (Total)	4 030 005	5 991 475	1 961 470

Data from FAOstat accessed 2016-06-27

FAO (2006) present the same trends, quite natural as they use the same data source as in this analysis. They show the highest concern for the trends in production for poultry, and second for pig production. The reason is that they, like people, are monogastric animals, which implies that these animals compete with humans to a substantial degree. Their staple feeds, cereals complemented with protein feeds,

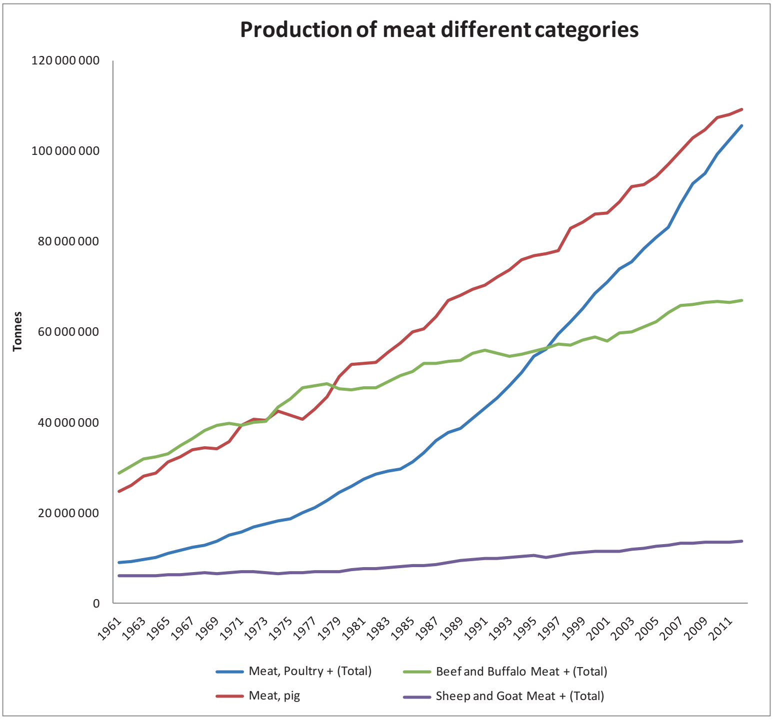

Fig. 4.28 The global production in tonnes of different meat categories (Data from FAOstat 2016-06-27)

could just as well be used as food directly for humans. Ruminants, like cattle can utilise other parts of natural and agro-ecosystems with otherwise low capacity to feed people.

Typically, around 30% of the feeds in poultry production are protein feeds like soybean, and 15% in pig production. In poultry production, typically around 1.5–2.0 kg feeds are used per kg meat produced, in pig production the amounts double. See also typical feeding rations presented in FAO (2006) for poultry and pig production for different nations and regions.

Table 4.18 and 4.19 show an increased production of pig meat in Asia from 1980 to 2012 with an increase of 45 million tonnes of pig meat when global production increased by 56 million tonnes; and 33 million tonnes for poultry meat when global production grew by 80 million tonnes. If we use round figures this implies that the increase in the demand on soybean as feed in Asia from 1980 to 2012 is as follows:

- Pig meat production: 45 million tonnes * 4 kg feed per kg meat * 0.15 as the fraction of protein feed as soybean → 27 million tonnes soybean
- Poultry meat: 33 million tonnes * 2 kg feed per kg meat * 0.30 as the fraction of protein feed as soybean → 19.8 million tonnes soybean.

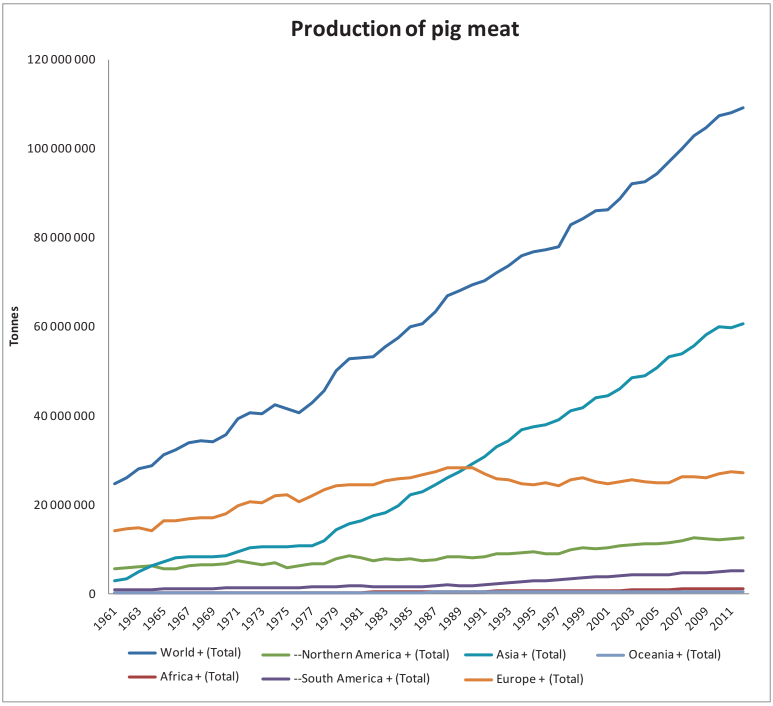

Fig. 4.29 Production of pig meat in tonnes from 1961 to 2012 on the global level and for major geographic regions (FAOstat, accessed 2016-06-27)

Table 4.18 Production volumes for pig meat in tonnes for 1980, 2012 and the change during the period on the global level and for major geographic regions

	1980	2012	2012–1980
World + (Total)	52 676 913	109 122 261	56 445 348
Africa + (Total)	342 198	1 198 636	856 438
North America + (Total)	8 570 200	12 553 707	3 983 507
South America + (Total)	1 740 777	5 288 964	3 548 187
Asia + (Total)	15 807 086	60 593 431	44 786 345
Europe + (Total)	24 479 997	27 226 500	2 746 503
Oceania + (Total)	297 547	500 484	202 937

This sums to 46.8 million tonnes soybean. If we assume that the average yield of soybeans are 2.2 tonnes per ha, and that 85% of the bean gives soybean, then the increase in production of pig and poultry meat in Asia increased the demand on land for soyabean production in South America by 25 million ha. From 1990 to 2012 the area of arable land increased by 37 million ha in South America (See Table 4.10). This numerical example suggests that the increased production of pig and poultry

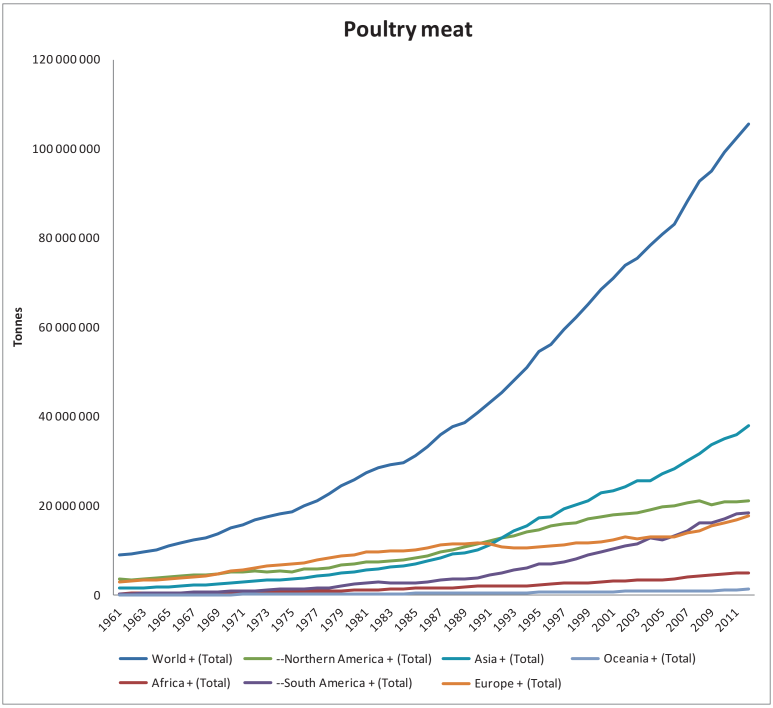

Fig. 4.30 Production of poultry meat in tonnes from 1961 to 2012 on the global level and for major geographic regions (FAOstat, accessed 2016-06-27)

Table 4.19 Production volumes for poultry meat in tonnes for 1980, 2012 and the change during the period on the global level and for major geographic regions

	1980	2012	2012–1980
World + (Total)	25 947 107	105 636 805	79 689 698
Africa + (Total)	1 055 573	4 957 575	3 902 002
North America + (Total)	7 014 294	21 028 912	14 014 618
South America + (Total)	2 410 842	18 421 797	16 010 955
Asia + (Total)	5 216 398	37 976 691	32 760 293
Europe + (Total)	9 115 045	17 722 230	8 607 185
Oceania + (Total)	353 039	1 275 451	922 412

meat in Asia is one important driving factor behind this development, which eventually contributes to tropical deforestation.

Figure 4.31 presents production of beef and buffalo meat from 1961 to 2012 on the global level and for major geographic regions.

Table 4.20 presents the production volumes for 1980, 2012 and the change during the period on the global level and for major geographic regions.

The increase in global production from 1980 to 2012 was 20 million tonnes, in Asia it was 13 million tonnes, in Europe the production dropped by 40%.

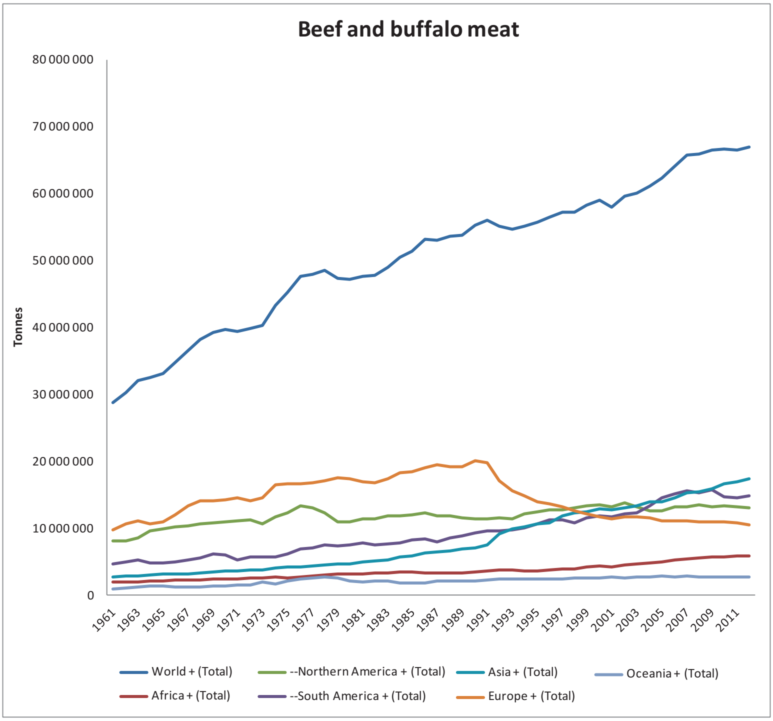

Fig. 4.31 Production of beef and buffalo meat in tonnes from 1961 to 2012 on the global level and for major geographic regions (FAOstat, accessed 2016-06-27)

Table 4.20 Production volumes for beef and buffalo meat in tonnes for 1980, 2012 and the change during the period on the global level and for major geographic regions

	1980	2012	2012–1980
World + (Total)	47 172 698	66 885 945	19 713 247
Africa + (Total)	3 161 221	5 883 381	2 722 160
North America + (Total)	10 969 771	13 053 232	2 083 461
South America + (Total)	7 507 599	14 879 698	7 372 099
Asia + (Total)	4 721 634	17 355 577	12 633 943
Europe + (Total)	17 407 555	10 428 704	−6 978 851
Oceania + (Total)	2 077 247	2 748 389	671 142

4.5 Production of Specific Important Crops

There are many very important crops produced globally. Some are grown in most parts of the world, while others are more locally used. One very important crop is soybean, which is produced in many different climate zones.

4.5.1 Soybean

One advantage with soybean is the high content of very balanced proteins, making it a possible replacement for animal meat to a great extent. The protein content is approximately 40% and there are eight essential amino acids in the protein.

In 2009, the global production was 222 million ton (FAO statistical database 2009). A lot of this is used as animal craft food, but if it was distributed it to all humans, it would mean approximately 100 gram of protein per person and day, which is principally more than needed. Now only 10% is used as food for humans directly (www.soyatech.com/soy_facts.htm. 2010-12-12) while the rest is used to feed 18.6 billion chickens, 1.4 billion cows and bulls and 940 million pigs worldwide. As already mentioned, soybeans are produced in many countries. In most cases this is positive, but in some cases it can also be seen as a problem like in, e.g. Brazil where rain forests are taken down to give space for soybean plantations. As always it is important to find long term sustainable production methods for the very important and good crops.

4.5.2 Rice

For another important crop, rice, this may be even more critical.

Rice is primarily produced in tropical and subtropical countries. A problem is that it is often produced under water which causes anaerobic conditions, and thereby production of methane as a negative by-product as it is a strong green-house gas. Still, there are methods for production of rice that avoid most of this but tradition is strong, as the methods mostly used have been in operations for thousands of years principally.

Global production of rice was 687 million tons in 2009; 192 million tons were produced in China where the average yield was 6.6 ton grain/ha,y. This is a high yield and can be compared to Republic of the Congo with on average 0.75 ton grain/ha,y. The global average is 3.9 ton/ha,y. With intensive irrigation Australia reached 9.5 ton/ha,y and Egypt 8.7 ton/ha,y. Due to this, 75% of the production of rice is harvested at 55% of the land area irrigated, and thus irrigation is also very important for increased production in other areas.

The second biggest producer globally is India with 131 million ton/year produced in 2009. The yield still is only 45% of that in China, so the potential for increased production is very high. If India reaches the same productivity as China this could feed another 400 million people with staple food. The production in Indonesia is in-between China's and India's while the total production was 64 million tons in 2009.

Thre are many other major producers of rice, the most important food crop alongside wheat from a human feeding perspective. It is the most important staple food in Asia, Latin America and Africa, which represent approximately half of the global population. Bangladesh produced 45, Vietnam 39, Thailand and Myanmar both 31, Philippines 16, Brazil 13, Japan 11 and Pakistan 10 million tons in 2007.

The world production of rice increased continuously from about 200 million tons of rice in 1960 to 678 million tons in 2009, and it should be noted that 95% is produced in developing countries.

In official statistics only the grain is counted. In reality, rice straw gives approximately the same amount of biomass as grain in ton Dry substance/ha,y; with 8 ton DS/ha,y of grain, which is less than in Australia and Egypt today, 8 ton DS /ha,y of straw could also be produced. (http://www.nationmaster.com/graph/agr_gra_whe_pro-agriculture-grains-XXX-production XXX is the crop type asked for, wheat, corn, rice etc.). For the total world production this means some 700 ton DS of straw that can be used for energy purposes as well as for soil enhancement, if converted by microbial processes like ethanol or biogas production. At least half could be converted to bio-fuel. As already mentioned there are methods to grow rice without production of large amounts of methane and hopefully these methods will be implemented on a large scale in the future.

4.5.3 Wheat (Triticum spp)

As already mentioned, wheat is the most important cereal alongside rice as a food for humans. The world production varies from 1 year to the next, but is currently around 690–700 million tons per year. The major producer is China with a production of 114 million tons produced in 2009. ("Major Food And Agricultural Commodities And Producers - Countries By Commodity". Fao.orghttp://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor, downloaded 2009).

India produced 81 million tons in 2009 (79 million tons 2008), the USA 60 in 2009 (68 million tons 2008) and Russia 57 million in 2009 (64 million tons 2008). It is obvious from the figures above that the variation is significant between years. Some years good harvest in one country can balance low harvest in another, but not always, which makes it necessary to store grain from 1 year to the next. In some countries this has proven to be quite difficult as mould and rats can destroy large quantities.

We said that there is approximately as much straw as grain from rice. This is also the case for wheat, and here the straw is produced in the range of 700 million tons/y, corresponding to some 3000–3500 TWh/y heating value if used as fuel. In most countries straw can be utilised much better for energy purposes than is the case today. In, e.g. China it was very common to burn straw in the fields to recover inorganic nutrients in the ash, while the organic material only caused air pollution. This is less common in China after a law prohibiting it a few years ago, but still very common in many areas.

Other major producers of wheat are France with 39, Canada with 29, Germany and Ukraine both with 26, Australia and Pakistan both with 21 million tons produced in 2008.

4.5.4 Corn (Zea Mays)

Corn or Zea Mays is another very important food crop. The biggest production is in the US with a production of 333 million tons/year (2009) followed by China with 163 million tons/year. Brazil produced 51, Mexico 20, Indonesia 17.6, India 17.3, France 15.3, Argentina 13.1, South Africa 12 and Ukraine 10.5 million tons in 2009. Altogether 817 million tons were produced in 2009, which is even more than for rice and wheat. Also, for Mays the blast portion is significant, even more so than grain. This should make a potentially good substrate for both ethanol and biogas. A lot of the grain is used for ethanol production in especially the US where many farmers survive on production of ethanol corn in the mid-west. Without the possibility to sell corn for ethanol production many farmers would be bankrupt in this region.

Many crops are sensitive to both diseases and different kinds of insects. Thus, Corn is interesting as it produces a very powerful antibiotic substance, 2,4-dihydroxy-7-methoxy-1,4-benzoxazin-3-one (DIMBOA) which accumulates in the crop just before it becomes ripe. This gives a natural defense against many pests, insects, pathogenic fungi and bacteria.

Corn is normally quite sensitive to droughts, and thus the soil type matters as well as the precipitation and possibility for irrigation (Monsanto 2011). Gautam, Gustafson and Wicks (2011) grew different sub species of Maize and saw a variation in the productivity from 11 to 21 tons DS/ha for similar growing conditions. Here, it was the total biomass production that was measured. This indicates that different species have very different capabilities, and combined with optimal conditions the production can be significantly improved in the future.

Corn has been genetically modified, especially in the US and Canada, to be more resistant to draft ect. Actually 85% of all corn produced in 2009 was genetically modified in these two countries. In Europe, this is not allowed today and genetically modified crops cause some friction in the trading between the countries.

4.5.5 Barley, Rye and Oats

Some other crops are common in especially northern countries. Russia produced 15.5 million tons barley 2009, while Canada produced 12.2 million tons, Ukraine 8.0 million tons, Turkey 7.0 million tons million tons, Australia 7.0 and the USA 6.0 million tons. Russia also produced 5 tons rye and 6.0 tons oats while Poland produced 3.2 million tons rye, Canada 3.7 million tons oats and the US 2.1 million tons oats in 2009.

4.5.6 Oil Crops

Oil crops are important for food use in different ways, but also as raw material for bio-diesel. In 2006, 47 million tons rapeseed oil was produced globally. The EU27 produced 18.1 million tons, China 12.2, Canada 9.1, India 6.0, Germany 5.3, France 4.1, the UK 1.9 and Poland 1.6 million tons. (http://www.soyatech.com/rapeseed_facts.htm). Most rapeseed oil is produced in northern areas like north of the Alps in Europe. In southern countries, olive oil is more common. The second largest vegetable oil type produced is palm oil with 41.3 million tons produced in 2007/08 and soybean oil with 41.3 million tons. Several other types were also produced in significant quantities like sunflower 9.9, peanut 4.8, cottonseed 5.0, palm kernel 4.9, coconut 3.5 and olive oil 2.8 million tons according to Oilseeds (2009).

We have already mentioned that the soybean is a major source for protein, but oil is also produced from it. While most of the protein is used as fodder for animals, 95% of the oil is used as edible oil.

World soybean production, including oil, increased by over 500% in the last 40 years.

4.5.7 Sugar Cane

Sugar cane is bigger in production volume than the other food crops. However, it is not as important as a food crop. Much of the sugar is used as addition to food, but a lot is also fermented to produce ethanol in, e.g. Brazil. FAO (Crop production, 2010) estimates that about 23.8 million hectares were cultivated with sugar cane in more than 90 countries. The total harvest globally was 1.69 billion tons in 2010. Brazil is the leading producer followed by India, China, Thailand, Pakistan and Mexico. Although sugar is considered less healthy to consume, there is still a large demand for it and sugar cane accounts for 80% of sugar produced while sugar beets produce most of the rest. In Brazil, the bagasse is also used as fuel for the distillation of ethanol, which makes it very environmentally friendly from a green-house gas perspective.

4.5.8 Cassava

Cassava is very important as a staple food in Africa where more than 30% of it is grown. The total production was 136 million tons in 1985. In 2005, it was 203 million tons. Of this 110 million tons were produced in Africa, 34 million tons in Latin

America and the Caribbean. Asia produced 56 million tons. (http://siteresources.worldbank.org/INTAFRICA/Resources/257994-1215457178567/Cassava_Profile.pdf, 2006).

Cassava is also considered to be a good crop for ethanol production.

4.5.9 Energy Crops

There are also a number of other important crops. We can see a few crops that can be utilised for energy purposes in Table 4.21 below.

In the table several crops are marked with C4. C4 crops have a different metabolic pathway compared to most other crops known as C3 type. C4 crops can utilise high concentrations of CO_2 and increase production when the content of CO_2 rises. C3 crops have difficulty handling increased concentrations of CO_2 because it inhibits its metabolism. Generally, C4 crops also have much higher production rates, and thus are very important. The efficiency from sun shine to hydrocarbons is 0.1–0.5% for C3 crops and 1–5% for C4 crops.

4.5.10 Quorn

In the future, it may be useful to look for new alternatives to replace meat. One such alternative is Quorn, which is a fungi grown in fermenters. The product has a consistency and taste similar to chicken meat. You can find more about the product

Table 4.21 Different energy crops

Name	In Latin	Yield t/ha DM	Climate zone
Fodderbeat	*Beta vulgaris rapacea*	20.0–50	TE
Giant knotweed	*Polygonum sachalinensis*	20.0–30	EU/AS 1/2 undergrd
Giant reed	*Arundo donax*	20–40	ME,PE grass,
Microalgae	*Oleaginous spp.*	1.0–20	Manyt types,oil
Miscanthus	*Miscanthus spp.*	10.0–40	C4,Eu,SEAsia,PE
Sorghum	*Sorghum bicolor*	14.0–40	C4,TE-TR,AN, 4 m
Sweet sorghum	*Sorghum bicolor*	12.0–45	C4,EU,USA,TR-TE
Sorrel	*Rumex acetosa*	10.0–40	PE,2 m,TE,Tolerant
Sugarbeet	*Beta vulgaris altissima*	8.0–30	TE
Sugarcane	*Saccharum officinarum*	16.0–73	C4,PE,ST/TR,>1500/y
Water hyacinth	*Eichornia crassipes*	30.0–90	PE,TR/STaquatic herb

Below we can see the explanation of the abbreviations used in the table:
ME mediteranian, *TR* tropical, *ST* subtropical, *TE* tempered, *CO* continental, *CE* central European, *NO* northen climates, *Am* America, *NAm* North America, *SAm* South America, *EU* Europe, *AR* arid areas, *AS* Asia, *IN* India, *AF* Africa, *PE* perennial, *AN* annual, *BI* biennial, *C4* C4-type of crops

Quorn at (http://www.quorn.com/). In 2011, 17 000 tons was produced. The feed stock is primarily starch with the addition of nitrogen salts, phosphate, trace elements and air. The product is high in protein, but also in RNA, which has to be removed before humans can eat it. The producer developed a large library of recipes for different meals with Quorn as a base component. The volume expansion has been slow, but there is now discussion about building an additional production line. As the food is an efficient replacement for meat with a vegetarian alternative this must be seen as a very interesting alternative.

4.6 Consumption of Food

4.6.1 Cereals and Meat

Table 4.22 presents data for the consumption of food from some major categories in terms of energy (kcal per capita and day as supply according to the definition by FAOtstat).

The supply increased from 2194 to 2868 kcal/capita and day from 1961 to 2011. Vegetal products dominate with 2362 kcal in 2011, while animal products provide 507 kcal. Cereals are the most important group with vegetable oils as second and sugar and sweeteners as the third group. Bovine meat and milk remained constant from 1961 to 2011, while intake of pig meat and poultry meat increased.

Table 4.23 presents the corresponding information regarding protein supply.

In 2011, the total supply per capita and day was 80 g, vegetal products contributed 49, cereals 32 and animal products 32.

The increase in protein from animal products is for pig meat and poultry meat in the table. The global average supply from bovine meat and milk has remained constant from 1961 to 2011.

Table 4.22 Consumption of food on the global level for some major categories in terms of energy (kcal per capita and day as supply according to FAOtstat definition)

	1961	1986	2011	2011–1961
Cereals – Excluding Beer + (Total)	1086	1310	1296	210
Starchy Roots + (Total)	175	128	141	−34
Sugar & Sweeteners + (Total)	192	237	229	37
Vegetable Oils + (Total)	113	207	280	167
Vegetal Products + (Total)	1856	2185	2362	506
Bovine Meat	39	46	40	1
Milk, Whole	94	83	96	2
Pigmeat	46	82	120	74
Poultry Meat	11	25	57	46
Animal Products + (Total)	338	405	507	169
Grand Total + (Total)	2194	2590	2868	674

Table 4.23 Consumption of food on the global level for some major categories in terms of protein (g per capita and day as supply according to FAOtstat definition)

World + (Total)	1961	1986	2011	2011–1961
Cereals – Excluding Beer + (Total)	28	33	32	4
Starchy Roots + (Total)	3	2	2	0
Sugar & Sweeteners + (Total)	0	0	0	0
Vegetable Oils + (Total)	0	0	0	0
Vegetal Products + (Total)	42	45	49	7
Bovine Meat	4	4	4	0
Milk, Whole	5	4	5	0
Pigmeat	2	3	5	2
Poultry Meat	1	2	5	4
Animal Products + (Total)	20	25	32	12
Grand Total + (Total)	62	70	80	19

Table 4.24 Meat consumption today and prediction for the future

Year	2010	2020	2030	2050	Growth 2010–2050
Human population billions	6.83	7.54	8.13	8.91	
(*Consumption million tons per billion people*)					
Bovine meat	9.85	10.25	10.93	11.93	121%
Ovine meat	1.94	2.08	2.28	2.64	136%
Pig meat	14.98	15.29	15.98	15.79	105%
Poultry meat	12.58	14.72	17.65	21.69	173%
Dairy	96.24	100.19	106.77	116.55	121%

Sources: FAO, 2006c; World Population Prospects, 2002. Some calculations made by the authors

As a population becomes wealthier the trend is to eat more meat. Meat is more costly from both an energy perspective and economic perspective to produce, which makes it attractive if you can afford it. In Table 4.24 we can see the predicted consumption from 2010–2015 according to FAO (2006c).

What we can see is a significant increase long term if the development follows patterns similar to the development over the last 50–70 years. To produce 1 kg of cow meat, some 20 kg of primary food must be fed to the cow and approximately half of that for pig meat; thus, creating significant losses from an energy perspective compared to eating cereals directly.

4.6.2 Capture and Consumption of Fish

Fish and other animals from sea and lakes are important as they are healthy and the main food for many people living in coastal areas. In Table 4.24 we can see the figures registered for different kinds of fish and other aquatic organisms.

Table 4.25 World capture of fish 2007 given in tons

	Inland fisheris	Marine fisheries	Total
Fresh water fish	8695	23	8718
Diadromous fish	341	1444	1785
Marine fishes	82	65 627	65 709
Crustaceans	474	5367	5840
Molluscs	383	7182	7564
Other	61	388	449
Total	10 035	80 029	90 064

From Table 4.25 we can see that marine fishes are the most important from a volumetric perspective. The figures shown probably do not represent all fish caught for various reasons. Over fishing with new more effective methods is a big threat to the production, but now water pollution with, e.g. enormous amounts of plastic is a new threat. In some areas it has been possible to change the trend like outside Canada and in the Baltic Sea, but when one problem is addressed new ones are detected, and the struggle proceeds.

During the last few decades fish farms have become quite common and the business is growing. As normally a predator type of fish is grown like salmon, they need protein rich food. Today, a lot of the fish taken up is actually used for this purpose. Other fish considered too small are usually sent back to the sea, but many of them are hurt so they do not survive, and thus are wasted. More precise fishing methods are needed to avoid this.

Generally, we can see that fishing is a common resource claimed by many, which makes it very competitive, and the need for international agreement is important. Sometimes this becomes true, but sometimes not.

In the book Farmageddon – the true cost of cheap meat by Philip Lymbery and Isabel Oakeshott [Boolsbury, ISBN 978 1 4088 46346, 2014] the authors discuss animal production from different perspectives. At farms 70 billion animals are produced worldwide every year. They consume 30% of the world's cereal harvest (in rich countries even 70%), 90% of its soybean meal and up to 30% of the global fish catch. This could be food for billions of humans. [Msangi S and Rosegrant M: world agriculture in a dynamically-changing environment:I:FPRI's long term outlook for food and agriculture under additional demand and constraints, paper written for FAO conference 2009 in Rome]. Around 100 billion farmed fish are produced annually. This can be compared to all chicken, cows, pigs and similar which are all together 70 billion. In 2009, 80 million tonnes of chicken meat was produced from 55 billion chickens. Fish farming produce 70% of that amount using 100 billion animals. In 2008, 23% of the fish catch was used to feed farmed fish [Henk Westhoek et al.: the protein puzzle – the consumption and production of meat, dairy and fish in EU, PBL Netherlands environmental assessment agency, the Hague, 2011]. In 2009 nearly half of the total supply of fish globally came from fish farms. Asia produces 90%, while Europe 4.5% and Latin America 3.3%. Another aspect is that fish are caught in one area but often consumed far away. The UK for instance consumed 135 000 tonnes of fish meal in 2010; 1/3 came from Peru.

The areas available for crop production limit our possibilities to produce food. The most optimistic estimates on land that could be used with enough rain is 15.6 million square kilometers. This is roughly equal to the existing cultivation land area [OECD-FAO: Agricultural outlook 2009–2018: highlights, 2009], which means we could principally double the total area.

The World Bank makes more modest estimates: 4.45 million square kilometers [Deininger K.,Byerlee et al.: Rising global interest in farmland: can it yield sustainable and equitable benefits? Worldbank, 2010]. Here, it is also stated that already cultivated land is 14 million km^2, from which 4.5 million is suitable for food production but almost 11 million needed for forests and other purposes. Totally, this means there is ~30 million km^2 available for rain-fed crop production world-wide. They also gives the figure that an intensive chicken farm can produce 150 000 chickens per year at 892 m^2, but another 90 hectares of arable land is needed to produce the cereal to feed the chickens.

David Pimentel at Cornell univ. calculated that conventional crop production in the US consumes 6.3 barrel of oil per ha; 2/3 of this is for production of the fertilisers and other chemicals (David Pimentel: impacts of organic farming on the efficiency of energy use in agriculture: an organic center state of science review. The organic center, august 2006.). The Cornell research group also claims that if 10% of all US corn (maize) were grown organically 4.6 million barrels of oil could be saved per year. They also calculated how much energy is put in, in relation to the energy value of products and presented the figures: 4:1 for harvested maize, 2:1 for harvested wheat while for beef production it was 40:1, for pig 14:1 and for chicken 4:1. One tonne of US produced maize consumes one barrel of oil to produce [World Bank development report 2008. Agriculture for development, Chap. 2, http://siteresources.worldbank.org]. This is a significant amount and food production consumes 7% of America's entire energy usage.

From 1970 to 1990 world grain production grew by 64%. From 1990–2009 the increase was only 24%. Predictions are made that the number of animals will almost double by 2050 mainly at factory farms. This livestock industry already contributes 14.5% of man-caused green-house gases emissions.

Around 124 million people in 118 developing countries suffer from vitamin A deficiency. Just in Asia the figure is 90 million. Golden rice is genetically modified by adding genes to produce vitamin A. In 2008, 13.3 million farmers in 25 countries — 90% smallholders in developing countries — grew genetically modified crops on 125 million ha; 50% of maize and 90% of soybeans are genetically modified species. In the US 40% of the maize goes to animals and 85% of this is GM. In China, scientists have introduced human genes into 300 cows to produce milk that is similar to human breast milk. This should stimulate the immune system of babies. Whether GM is a solution of great importance or a potential problem is debated. It is easy to see the advantages, but possible disadvantages may take a long time before seen and thus are difficult to valuate.

In California 443 000 full-time jobs are in dairy-linked industries. Each cow can produce more than 10 000 l of milk per year, but also create as much waste as 50 humans per year. In November 2011, there were 1620 dairy farms in California with

1 750 000 cows according to the California Milk Advisory Board (CMAB). This creates $63 billion per year as business activities.

In China, 70% of pigs are in family farms. Still, just because it is a family farm does not automatically mean that the environment for the pigs is always good.

4.7 Environmental Recycling Agriculture (ERA)

By recycling P, N and K in the right way harvests can be high without leakage of nutrients into waters.

At Nibble farm close to Vasteras in Sweden the same harvest of cereals was achieved with half the amount of N by distributing the fertiliser more evenly and in green plants, roughly 1 dm high, instead of at naked soil. Then also almost no emission to water and air was measured. In Fig. 4.32 we see the Baltic Sea region.

Fig. 4.32 Countries participating in a local project on ERA and measurement positions. All in the Baltic Sea region (From http://www.mapsofworld.com/free-maps/)

The primary target for the ERA concept was the Baltic Sea and the surrounding countries. To obtain balance we should reduce the consumption of meat by some 60–70% according to estimates made in the project. The production of crops will be reduced by 20% per hectare, but by reducing the number of animals more cereals will be available for humans. Thus, we will still get the food needed for the population around the Baltic Sea. At the same time the leakage of P would be eliminated totally and the amount of N halved. Thus, this would give the strongly eutrophied Baltic Sea a long term recovery. In Sweden there is a lot of animal farming in the south, but a lot of cereal production in the Stockholm-Malardalen region. By sending manure from south to middle Sweden a better balance would be achieved as well (Marcus Larsson and Arthur Granstedt 2006).

This example was presented to discuss how environmental issues can be addressed by changing the way of farming, but also what effect this could give on total production.

4.8 Biomass Production in Northern Europe

There are large biomass resources in the North European countries and if we also include Russia the word huge better describes the situation. If we look at the biomass production and use the average values for production of cereals in the official statistics and double these figure, we get a rough estimate of the production in ton DS per ha. By multiplying this figure with the production area in each country and settinh the higher heating value to 5.2 MWh/ton DS, we get the figures in the table below for cereals. For forestry we used 3 ton DS/ha, y as the production of biomass, which is the average in Sweden. In reality, the productivity varies but it gives an order of magnitude. The production of biomass is then compared to the energy use in each country, and a surplus (positive figure) or deficiency (negative value) is given for each country in TWh/y. This is presented in Table 4.26.

We can see in Table 4.26 that Germany, the Netherlands, Belgium and the UK have major deficiencies while most of the other countries have significant surpluses. Concerning use for energy purpose, we still do not see this surplus as most is not utilised that efficiently. One reason is that wood is, e.g. used for pulp and paper, but this should sooner or later be converted to energy. Still, huge amounts decay in the forests and are never utilised. Much of this could be utilised without creating hazards for the environment.

4.9 Algae

Algae are another resource that is not used so much directly, but indirectly as food for many animals, which are later eaten by humans.

Table 4.26 Biomass production in relation to energy use in Northern European countries and Russia

2008/2009	Cereals including straw	Other Agro than cereals	Forestry	Energy use	Prod-use
	TWh	TWh	TWh	TWh	TWh
Austria	56	204	63	332	−10
Belgium	36	103	11	586	−436
Denmark	110	196	9	190	125
Esthonia	9	60	36	54	51
Finland	46	188	359	353	240
Germany	537	1207	179	3353	−1429
Netherland	22	153	6	797	−617
Norway	10	86	163	297	−37
Ireland	22	275	12	150	159
Latvia	18	135	54	45	162
Lithuania	41	189	35	92	173
Poland	322	1108	151	979	602
Sweden	57	258	457	496	275
Switzerland	11	100	20	267	−136
UK	240	1128	47	2085	−669
Russian Fed	1027	16 249	13 107	6868	23 515
Belarus	88	661	140	281	607

(Own calculations based on areal data from World Bank for each country)

Araujo et al. (2011) have evaluated different micoalgal strains for production of oil and biomass while Gouveia and Oliveira (2009) have studied microalgae as a raw material for biofuels production. Lipid productivity in relation to other organics is of special importance here, and has been studied by e.g. Griffiths and Harrison (2009). Jorquera et al. (2010) compared energy life-cycle for microalgal biomass production in open ponds and photobioreactors, which is of interest both for biomass production as such, but also for water cleaning, which has been investigated by Park and Craggs 2011a; Park et al. 2011b. Quintana et al. (2011) and Tan et al. (2011) have investigated cyanobacter. These are not algaes but considered as "almost" algae as they can bloom in a similar way but also can take nitrogen from air, which can be of importance if low levels of nitrous compounds otherwise. The production of biomass is both a possibility.

Algae also can be used to produce important metabolites that can be used for e.g. medicine production. Cardozo et al. (2007) have presented an overview of some metabolites from algae of economic importance. Carver et al. (2011) have studied among other hydrogen production in anaerobic co-digestion of microalgae and cellulose in thermofilic reactors. Some groups like Aresta et al. (2005) and Ho et al. (2011) have focused more on the CO_2 fixation in algae, which may have a significant impact on removal of CO_2 from the atmosphere.

Kelp is a very fast growing macro alga. It can grow by 0.5 meter per day under favorable conditions. At the Californian coast it exists in large quantities as well as at Faeroe Islands in the Atlantic between Norway, Scotland and Iceland. Here, estimates give a volume of some 15 TWh of kelp (Ocean Forests, 2010). Plans exist for how to utilise this on a large scale.

Other interesting algae are micro algae which may double their weight in 1 day! A drawback for algae is that light is needed as they utilise sun shine to convert CO_2 and H_2O into hydrocarbons. Thus, the new type of very high efficiency LED-lamps coming to the market are of high interest. Today a LED lamp has roughly 1/10 of the electricity consumption compared to "old fashion" wire lamps, but within a few years we probably will have lamps consuming five times less than those of today". Then we can really start to utilise LED-lamps to make it possible to also produce algae in countries with dark winters to sustain production at least at some level year round.

Production rates for algae are given in, e.g. http://www.fao.org/docrep/003/w3732e/w3732e06.htm#b6-2.3.6.%20Algal%20production%20in%20outdoor%20ponds.

Here, we can see that many species can utilise high concentrations of CO_2, due to C4 metabolism, and thereby, e.g. utilise CO_2 in exhaust gas from power plants. In this way, we can combine production of new fuel with removal of CO_2. Since we also need nitrous compounds and phosphate it may be possible to combine waste water treatment with exhaust gas cleaning, which makes it economically interesting. As often the same company produces heat and power in cities, as well as cleaning the waste water, it should be not too difficult to make such systems come true.

Micro-algae like green algae produce large amounts of fatty acids and fatty oil, which from a human perspective is of interest as a bio-fuel. In Fig. 4.33 we see macro algae found at Code of Good Hope in South Africa.

Fig. 4.33 Macro algae from Cape Good Hope, South Africa

4.10 Crop Improvements

4.10.1 GMO

Since 1996, GM-crops haveincreased from almost nothing to 181 million hectars globally in 2014. This corresponds to approximately 10% of the 1500 million ha agricultural area. GM crops grow in 28 countries, where the US, Brazil, Argentina, Canada, India and China grow the most. The properties of highest importance are herbicide tolerance, insect resistance or combinations of these two. The most important GMO crops are soybeans, cotton, corn and rapeseed. In 2014, 82% of all soy harvested was GM, while cotton 68%, corn 30% and rapeseed 28% (James, 2014).

Only one GM crop is allowed so far in the EU. This is corn MON810, and has insect resistance, grown on 143000 ha; 92% of this was in Spain, while the rest in Czech Republic, Portugal, Slovakia and Romania.

Of the 181 million ha of GMOs grown in 2014 only 3.5 million ha were in Africa (South Africa, Burkina Faso and Sudan). Now in these countries, GMOs dominate (87% of corn and 92% of soy and 100% of the cotton in South Africa).

The insect resistant crops are primarily used by small farmers while herbicide resistance is typical for large scale farming in Africa. A huge future potential is also seen to develop other functions for the crops using GM-techniques in Africa.

A dilemma for GM-crops is the legal aspects. In the EU the critics demand the advantages of GM crops should first be proven before acceptance. The problem is that the GM crops are not allowed to be tested, and thus this verification is not possible to perform. Another aspect is that some GM crops are produced by only one supplier, and thus there is a monopoly, which causes commercial problems, especially in countries where the economy does not allow paying significantly higher prices, and thus are skeptical of the GM crops. The risk of spreading unwanted properties together with the wanted is a third concern for introduction of GM crops.

The difference between natural selection of species and the active modification by GM concerning agriculture in the EU has led to a 70% import of the protein fodder used in the EU, showing the dilemma the restrictive attitude towards the growing of, e.g. soybeans in the EU has caused.

It should also be noted that using insect resistant crops reduces the use of insecticides and thereby reduces the environmental impact, while the increased production gives complementary economic benefits. The total benefit per ha is 80–500 $/ha in the countries growing cotton and using GM, according to Klumper and Qaim (2014) and Vitale et al. in 2014 (highest in Pakistan 504 and China 470 $/ha). Here, the use of insecticides was 21–77% less and production increase 9–37%. Concerning selection of resistant species of Populus for energy crops has been studied by Zalesny et al. (2009) to investigate the interaction with environment.

4.10.2 Improvement of Harvest Yields

Approximately 40% of 5 billion ha arable land is more or less threatened according to the UN. By plowing we degrade the soil by 50–100 times the natural increase of the soil layer, which shows the negative impact especially where we have intensive agriculture, and the need to replace organics to the soil continuously.

Carbon content in soil increases with permanent grass but decreases if intensive agriculture is introduced with plowing. Rothamstead Research, UK has shown this at a couple of test sites.

Still et al. (2003) investigated the distribution of C3 and C4 types of crops globally. By growing C4 crops instead of C3 the harvest can be increased strongly in a relatively easy way. C4 crops are also favored due to the increase in CO_2 content in the atmosphere.

4.11 Use of Insects as Food

In many countries in Asia, Africa and Latin America insects are used as food for people or as fodder for animals. Also, insects are used to produce products like honey and silk. FAO made an interesting report on how insects are used (FAO 2012) or could be used in the future. The advantage with using insects is that the efficiency from input food to protein rich product is very high. Often we can get yield that is several times better than for even chicken, which is otherwise the best with respect to animals, much better than pig and cattle.

In China, insects are commercialised and sold on markets in most cities as seen in Fig. 4.34 from a market place in Beijing (photo Erik Dahlquist).

In the FAO report Edible insects, future prospects for food and feed security, by Arnold van Huis et al., 2013, a very good overview is made of the status today. According to the report at least 2 billion people have insects as part of their traditional diet. Over 1900 different species are reported as food types. Beetles (Coleoptrera) are the most frequently utilised group of insects with 31%, while caterpillars (Lepidopetra) makes up 18%. Bees, wasps and ants (Hymenoptera) makes up 14%, and grasshoppers, locusts and crickets (Orthoptera) follow close behind at 13%. The group cicadas, leafhoppers, planthoppers, scale insects and true bugs (Hemiptera) contributes with 10%, while termites (Isoptera) and dragon flies (Odonata) both have 3%, flies (Diptera) 2% and 5% is then divided between other species.

The efficiency of insect cultivation with respect to energy can be very high. In cricket farms a weight gain of 1 kg body weight per kg feed was reported. The conversion of crops into meat also reportedly emits less green-house gas than meat production normally does.

Mostly, insects are gathered in nature, but also a number of insects are farmed for food like crickets in Laos, Thailand and Vietnam. It is reported that there are about 20 000 cricket farms alone in Thailand. So far, primarily two species are produced economically in farms: Gryllus bimaculatus and Acheta domesticus.

Fig. 4.34 Insects as food in China

Some farms are also starting to produce black soldier flies.

Aside from being farmed, several species are also popular to eat in Africa and Latin America. In Malawi, three cicada species are very popular as food (Ioba, Platypleura and Pycna). Many lerp-building psyllids are found on Eucalyptus in Australia and used as sweet food by Aborigines. Pentatomid bugs are eaten in most countries south of the Sahara. Especially, pentatomids living in water are appreciated as human food after roasting; Mexican caviar, ahuahutle, is an example of this.

It is a bit difficult to understand in western Europe that ants are considered delicacies in many countries, like the weaver ant (Oecophylla spp.) in Asia, where it is also used as a biological control in mangoes. The larvae and pupae are used, but called “ant eggs”. The black weaver ants are used as nutritional ingredients in many health foods in south east China, Bangladesh, India, Malaysia and Sri Lanka. In Japan, the larvae of yellow jacket wasps (Vespula and Dolichovespula spp.) are eaten; they are called hebo.

In Niger in West Africa, grasshoppers are collected in millet fields and sold on local markets, where the price per kg is higher for the insects than for the millet!

In Latin America a small grasshopper, chapuline, has been used as local food for centuries, and is still used a lot in Mexico, especially in the Oaxaca valleys. Sphenarium purpurascens is a pest of alfalfa plants, but it is also an important local protein source. A family can collect 50–70 kg of grasshoppers weekly (Cerritos and Cano-Santana 2008). Thus, the chapulines are important as food, but a problem is that they may sometimes contain high amounts of lead.

In Kinshasa in Democratic republic of the Congo, caterpillars are an important food for many families. The average household eats approximately 300 g of caterpillars every week almost year round. Of the 8 million inhabitants in Kingshasa 70% consume caterpillars regularly.

In Laos, many water living insects are eaten like water scorpion, diving beetle, water scavenger, dragon fly and giant water bug. These are available year round, while other land living species are more seasonal.

Aside from being used as human food there is a strong potential to use insects as food for fish like salmon in fish farms and for poultry. It can then replace fish-meal.

An obstacle to use of insects as human food is the lack of legislation. This would be needed to give people generally a trust in eating it. Another aspect is documentation of food-value of insects such as how humans can absorb the protein from the insects. Also, investigation of the feed to meat analysis should be investigated and presented in a systematic way, as for other food stuff.

FAO also has a web portal about insects as food at www.fao.org/forestry/edibleinsects.

In Western Countries there are few insect farms. An exception is the farm of three brothers in Campbellford outside Toronto in Canada: Darren, Jarrod and Ryan Goldin. It is said to be the largest insect breeding farm in North America. http://globalnews.ca/news/2061255/ontario-cricket-farm-hopes-bugs-are-the-future-chefs-adding-insect-to-the-menu/

They started in March 2014 breeding crickets. Crickets require 12 times less feed and 13 times less water than cattle to produce the same amount of edible protein, and not nearly as much farmable land according to Goldin. The crickets are processed into flour that can be used in bread, salad dressing or vegetarian chili. This makes the other products healthier by adding protein and amino acids.

In Vancouver, Canada, in 2008 Vij's Indian restaurant already served ground roasted crickets as flour into Indian flatbread. Unfortunately, people did not order much of the dish — only around 10 dishes per night. In 2010, she then put crickets into pizza instead. This was not very popular either (http://globalnews.ca/news/2061255/ontario-cricket-farm-hopes-bugs-are-the-future-chefs-adding-insect-to-the-menu/) and after a year they removed the dish from the menu. "If insects should be appreciated in North American food it must be made so that it is as good as steak", the chef Dhalwala said. (http://www.coastweek.com/3822-culture-03.htm).

In Kenya, winged termites are fried and eaten. The huge amounts of nutritious insects that swarm at the onset of the rains are used. A cupful of termite, popularly known as "kumbekumbe", retails at 1 U.S.$ in the town according to Adhiambo, who sells termites for 15–20 $/day at the local market. http://www.huffingtonpost.com/2015/05/06/eating-bugs-mainstream_n_7206362.html. This is one of many examples given in the FAO report published in 2013. (2013 report published by the Food and Agriculture Organization of the United Nations). In the report we can read that two billion people in parts of Central Africa, Southeast Asia and Latin America, eat insects (entomophagy: the practice of eating insects) regularly and have been doing so for years. The most popular species as food are beetles, caterpillars, bees, wasps and ants.

Insects normally are high in protein which is produced much more efficiently than most animal protein, and less CO_2 is emitted. The farming also needs less land area and water for the same weight produced. Kevin Bachhuber, the owner and founder of Big Cricket Farms in Youngstown, Ohio, is optimistic about the market for insects in the US. One year after he launched his food-grade cricket farming operation, he said they see "a demand that is 100 times what they can supply." The interest is from restaurants, distributors and start-ups (http://www.huffingtonpost.com/2015/05/06/eating-bugs-mainstream_n_7206362.html). Rhino beetles or leaf-cutter ants are said to taste like bacon. If this is true it might be something to produce and make into new types of food. This might be a way to get Americans and Europeans to want to try insects as food.

PROteINSECT is an EU project enabling the exploitation of insects as a sustainable source of protein for animal feed and human nutrition (http://www.proteinsect.eu/). Here, fly larvae of two species are produced from organic waste. The volume of the waste can be reduced by 60% at the same time. The project has 12 partners from seven countries and is coordinated by the Food and Environmental Research Agency (FERA) in the United Kingdom. Another project is GREEiNSECT (http://greeinsect.ku.dk/). This project aims at mass production of insects as food in Kenya.

http://www.wageningenacademic.com/loi/jiff.

2015 a new Journal was started on the subject: *Journal of Insects as Food and Feed*, Online ISSN: 2352–4588. Volume 1, Issue 1, 2015.

A couple of other sources on the subject are given in http://www.foodinsectsnewsletter.org/ and http://www.eatinginsectsdetroit.org/

In Eskilstuna, Sweden, a demonstration plant is right now (2016) starting up, built on experiments in a pilot plant with 10 kg organic waste per day that has operated for several years at the Swedish Agricultural University in Uppsala. The demonstration plant will use 1000 kg/day waste, which was pressed through a screen to remove plastic, metal etc. before fed to boxes where larvae of American Soldier fly are added. The larvae increase rapidly in weight and after 2–3 weeks harvest is made of larvae. Some become flies and lay new eggs, that form new larvae, and so the cycle continues. From 1000 kg waste approximately 200 kg of larvae are formed, containing 30% fat and 40% protein of dry solids, and 200 kg residue is also passed on to a biogas production facility, where biogas is produced for vehicle transportation (Figs. 4.35 and 4.36).

The demonstration plant should be in operation by summer 2017, where scale up is made by Mälardalen University and Esksiltuna Energy and Environment, who also investigated an upgrade to the useful product.

4.12 Forest Resources

The total forest area in 2011 was 40 184 163 km^2. This is a huge area, but also not very homogenous. Some of the forests are plain softwood with spruce mostly. Others contain spruce and hard wood trees like birch. Some are dryer with mostly pine. Some are tropical with an enormous variety of different species! So from some perspectives forests are difficult to handle as a subject.

Fig. 4.35 Household waste sorted into different coloured bags and sorted automatically in Eskilstuna. The organic household waste is pressed through the press to the right, and the material that passed is used as feed stock to the fly larvae production (Photo Erik Dahlquist)

Fig. 4.36 From eggs over larvae to adult flies. From pilot plant at Swedish Agricultural University, Björn Vinnerås (Photo Erik Dahlquist)

However, forests have in common that the trees grow for a significant time period before they are harvested, which is different from most plants in agriculture. Fruit trees are the only difficulty, as they are normally trees but do not form what we call a forest. Still, the circulation of trees can be very different. In cold areas in northern countries the trees often stand for 80–100 years before being harvested, while Eucalyptus and Acazia may be harvested after 7 years when cultivated in subtropical or tropical areas. This gives very different properties of the wood and normally trees grown in cold climates, mostly soft wood, have long, strong fibres, while the fast growing trees have short, weaker fibres. Thus, their use can be differentiated to some extent. Usually dense species which grow slowly are better for use in buildings and furniture.

In Fig. 4.37 we see the percentage of forests in different geographic regions.

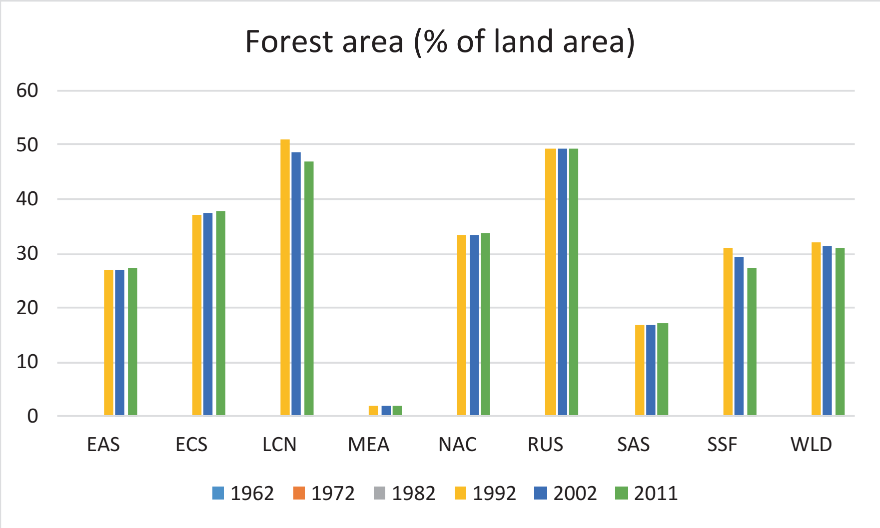

Fig. 4.37 Percentage of forests in different geographic regions

We can see that Latin America and Russia have very high percentages, but most other areas except South Asia also have large shares. Despite the high population density in South Asia, we note that the percentage of arable land is very high, and this is primarily due to forest area reduction. If we make the same type of distribution but on income levels instead (Fig. 4.38), the relatively equal distribution is astonishing.

Concerning resources, we noticed the distribution is not generally uneven between rich and poor countries. Differences are much higher within countries and due to climate and national borders do not reflect this, and national income and national basic resources do not correlate very well, at least not with respect to agricultural-arable land and forests.

Resources, such as oil and gas, can give high national income, but nations often suffer from poor distribution of the income on the population, and few countries use the income to develop the country. Instead the income is spent on consumption "right now". Some exceptions still exist like Norway, where the government invests income from oil by buying shares in international companies instead of spending the money short term.

Concerning forestry, we still see an important business with long term potentials in many countries, and thus it has potential to be much more important than, e.g. oil business long term (Carle and Holmgren, 2008) and (FAO Statistics, 2011). For agriculture this is even stronger, although industrialisation reduces the importance with respect to income for farmers. In many Western countries, only 2–3% of the population are farmers, where 200 years ago some 80% were farmers. Still, the production is perhaps 10 times higher per ha farmland. We still have not seen the same development for forests, but in the future we can expect more industrialised forest production as

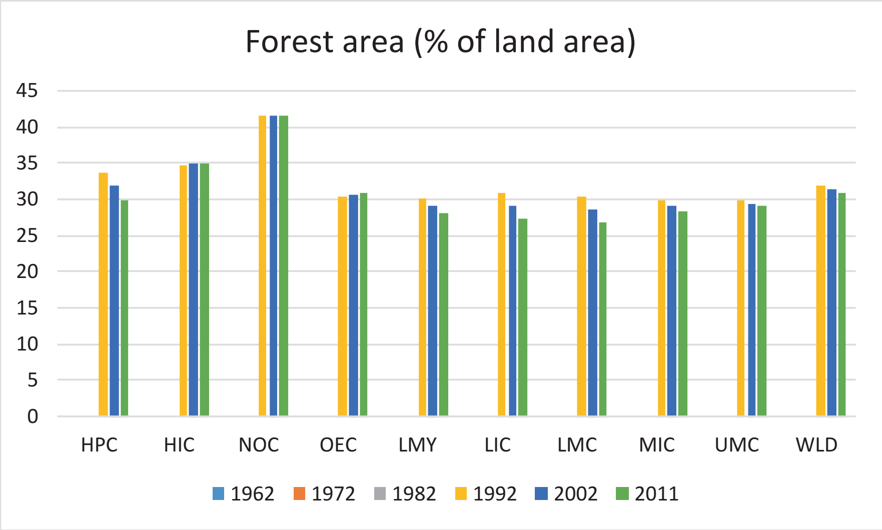

Fig. 4.38 Forest area as % of total land area

well, for good and bad. It is important to keep in mind biological diversity and robust crop systems avoiding too much mono-culture. If we look at how specific tree species like Alm-tree and Asken-tree are killed by specific moulds, and the present Banana species are predicted to be extinct before 2020 due to other moulds. What would happen if species like wheat and rice were attacked in a similar way?

4.13 Water Resources

Water is aside from food the most important factor for life, and food production is not possible without enough water. Therefore, it is a problem that the water as a resource is limited in many countries and regions. In North Africa and the Middle East, there is more oil than water, but there is the advantage that desalinated water can be produced by reverse osmosis using membrane filters and electric pumps. The electricity is produced from oil powered plants mostly, but a new trend is seen towards using more solar power, both PV and concentrated solar power (CSP).

In Fig. 4.39 we see the cost for production of fresh water in different regions. The cost varies significantly. Generally, the cost has increased globally since the 1980s, The variations depend on what resources are available in different countries as well as regions within countries, and how industrialised the water production is. In, e.g. South Asia, the cost is very low as people often do not pay at all for water. On the other hand, the water quality can also be very varied.

In Fig. 4.40 we see the overall renewable resources in different regions. The relevance for these figures can be questionable as the size of the regions are different.

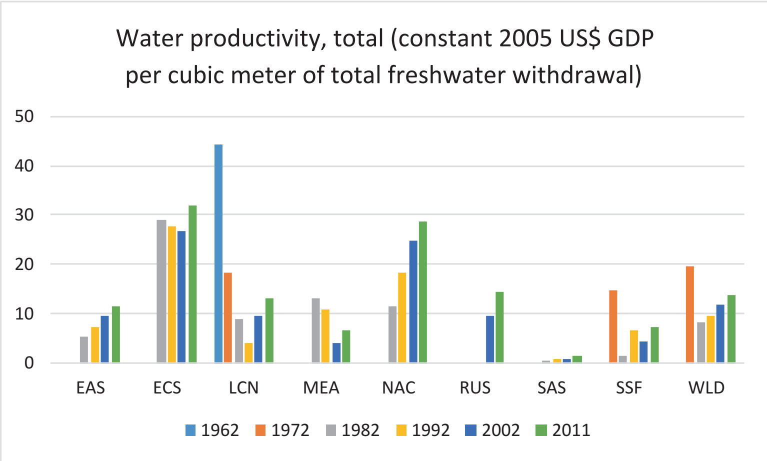

Fig. 4.39 Cost (US$/m³) for fresh water in different regions

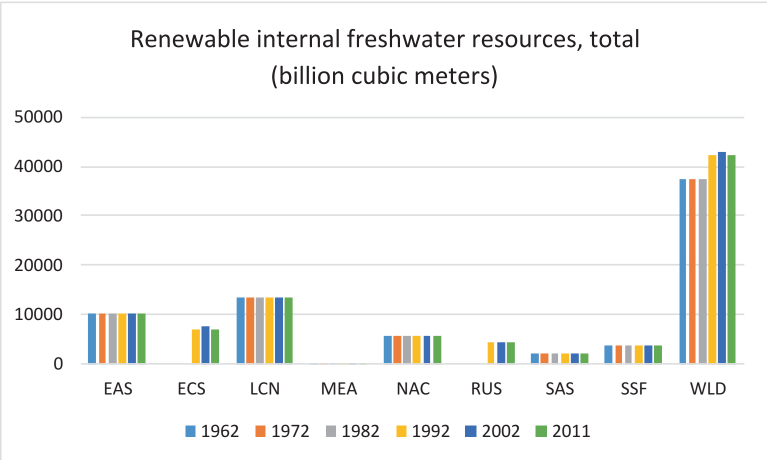

Fig. 4.40 Total renewable fresh water resources in different regions

Still, we can see that there will probably be a general shortage of fresh water in the Middle East and North Africa as well as in India. Otherwise, many countries and regions have shortage at least during some periods of the year even in regions with principally good resources like Europe. In countries like Spain and Greece, the situation can be similar to in Northern Africa, and in large cities like Mexico City and Beijing the shortage of fresh water has demanded major actions to counteract the shortage. In China, a big river was created taking water from the Nanyang area through Nanyang, Zhenzhou and up to Beijing. This became operational just a few years ago after 11 years of construction.

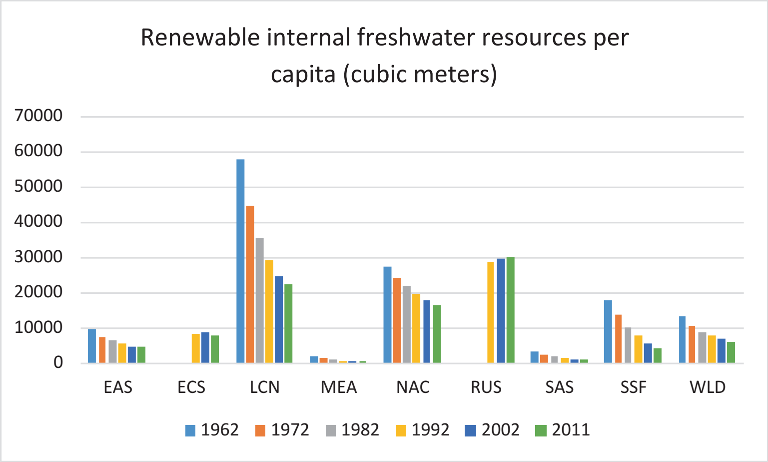

Fig. 4.41 Renewable fresh water resources as m³/capita in different regions

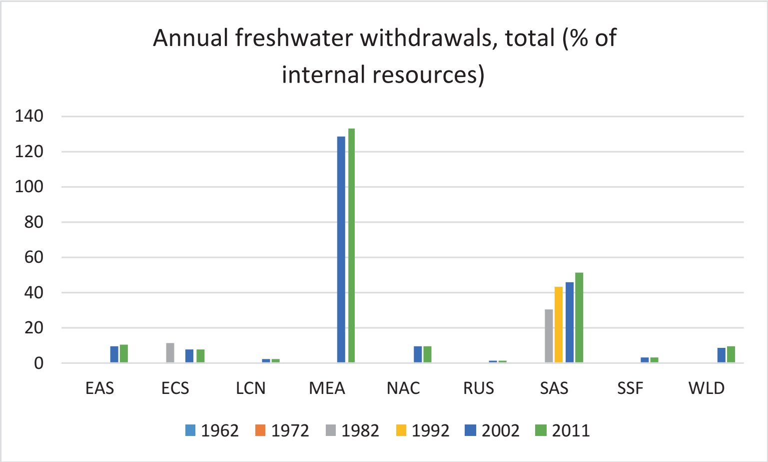

Fig. 4.42 Annual withdrawal of fresh water as percent of available resources

In Fig. 4.41 we see the corresponding figures for fresh water as m^3/capita in the same regions. Here, we see a strong variation between all regions, but also a trend towards lower volumes per capita in most regions, primarily depending on the population increase. Also, here we still see a huge difference within the regions, where big cities often get a shortage due to the huge increase in population.

In Fig. 4.42 we see the percentage of available fresh water resources that are utilised today. In the Middle East and North Africa, the consumption is significantly higher than available resources, while in South Asia a significant portion, some

50%, of available resources are utilised, but also in regions with principally good resources we see shortage locally, as already emphasised.

The amount of the withdrawal that is used for agriculture is seen in Fig. 4.43. Depending on region we see 20–90%, with a global average of 70%. What we can predict is that this figure will increase even further to increase production as ton/ha farmland area.

In Fig. 4.44 we see water resources for some important countries. High population density as in China, India and the EU (generally) also is reflected in low amounts of

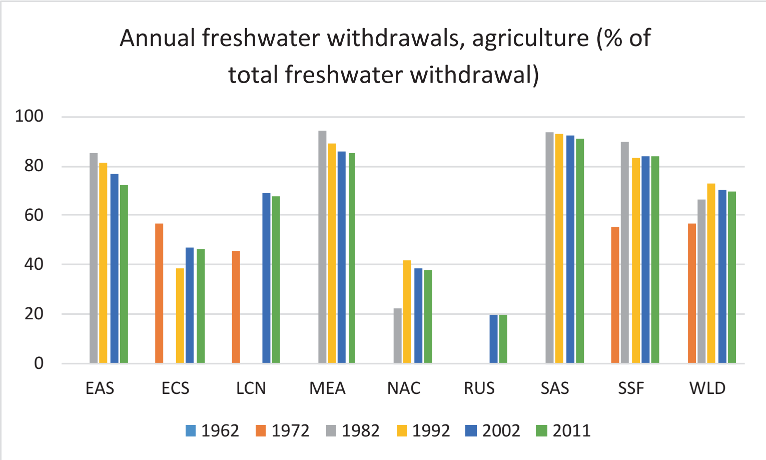

Fig. 4.43 The percentage of annual fresh water withdrawal that is used for agriculture in different regions

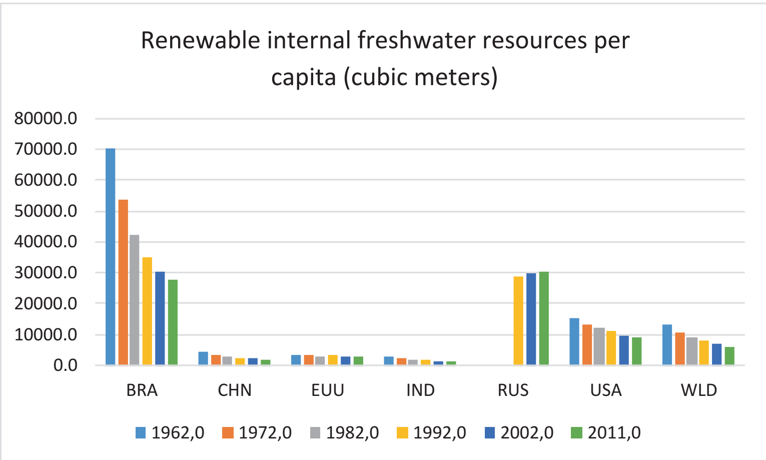

Fig. 4.44 Renewable freshwater in m^3/capita in some specific countries

Table 4.27 Renewable internal freshwater resources per capita (cubic meters)

Country code	1962	1972	1982	1992	2002	2011
BRA	70 103	53 743	42 486	35 046	30 202	27 512
CHN	4225	3263	2789	2415	2197	2093
EUU	3527	3285	3146	3182	3067	2973
IND	3090	2490	1977	1600	1343	1184
RUS				29 007	29 661	30 170
USA	15 107	13 426	12 164	10 986	9797	9044
WLD	13 199	10 680	8865	7918	6921	6124

Fig. 4.45 Available renewable fresh water resources as a function of income per capita. No correlation is seen on a national level

fresh water per capita, while some countries like Brazil, Russia and the US principally have huge amounts available. Still, we know that there is shortage in several southern and western regions in the US, like in California, which shows how important local conditions are for the water supply (Table 4.27).

One thing we can also see is that the water resources do NOT correlate to income per capita. Instead, it is the climate that determines how much water per capita there is. From a sustainability perspective, we still have the problem that water resources vary a lot between countries and regions. However, it is mostly those who already have scarce resources that will suffer most from increased global temperatures, while those with highest resources will be less affected.

In Fig. 4.45 we see available fresh water resources as a function of income per capita in different countries. Here, we can see that there is no correlation between income per capita and available water resources, at least not on a national level. On the other hand, there may be a big difference between available resources and individual income on a personal level inside many of the countries, especially in countries with many poor people, who often suffer from deficiency of at least clean fresh water in slum-areas.

4.14 Summary

In this chapter some data and trends for global agriculture and forestry were presented, based on data from FAOstat. The use of the natural capital land for different purposes such as arable land, permanent meadows and pastures, agricultural land and forests, are shown.

Use of inputs such as nitrogen fertilisers, phosphorus fertilisers and biocides are given. Key figures for major crop categories are provided, such as areas, production volumes, yields in relation to inputs of land and of fertilisers.

Production volumes for the most important animal production branches are also provided as well as data for supply of different categories of food in energy terms and as protein.

Results were presented on the global scale and on the level of major geographic regions. A lot of what is produced is actually never being utilised. In Karlsson-Kanyama (2004) and Karlsson, R. & Carlsson-Kanyama (2004) food losses and their prevention strategies in the complete chain from production, storage, distribution and in households is investigated. Some 10–20% at least in wasted even in the best cases in Sweden, and figures of 30% in the UK and 50% in the US have been shown in other studies.

Larsson, M. & Granstedt (2009) have investigated how ERA, Environmentally Recycling Agriculture could be performed in the Baltic Sea region in northern Europe. By reducing addition of fertilizers (N and P) the discharge to lakes and rivers can be reduced without loosing too much production capacity. A balance is seen around halvening the nutrients, which will mean a reduction of P by almost 100% from farmland, but a production decrease by some 20%. By decreasing the consumption of meat by some 50% could match this. An interesting alternative to production of animals then can be to produce Quorn (2012), a type of fungi, which reduces the demand for fertilizers and give something tasing very similar to meat.

Regarding forests (FAO statistics, 2011 and 2012), data on areas are easily found. However, we did not find data close to the level of detail as for agriculture. Therefore, the presentation regarding agriculture is more detailed than the one for forestry.

In the analysis global agriculture and forestry are treated as one gigantic farm, using the same approach and methodology as when supporting farmers in their choices in order to maximise their system performance in relation to available resources of land, labour and capital. In this chapter the focal points are the utilisation of the natural capital land, and some natural resources in the production of the ecosystem services food.

The results presented agree well with the ones in FAO (2006), which is quite natural as

- A similar competence in agricultural sciences and environmental sciences was utilised, and
- Both the analysis in this chapter and the one in FAO (2006) rely heavily on statistics in FAOstat.

Although the analysis here can only be made on a quite high, overall level, some interesting results are still provided. The applied approach can be fruitful when implementing strategies for sustainable development, as it is based on knowledge and methods in those disciplines that offer the competence of excellence for concerned systems and issues.

As an overall conclusion the capacity of global agriculture and forestry to support a global, sustainable development are judged to be good.

Some of the results are that

- An increasing animal production in Asia, e.g. pig and poultry production, drives a globally increasing production of soybean eventually increasing pressure for tropical deforestation
- The supply of milk and meat from cattle and buffalos per capita has remained stable from 1961 to 2011
- In relation to use of commercial fertilisers, the agriculture in Africa is productive, while the agriculture in Asia is unproductive
- The yields per ha are still much lower as averages in Africa than in other major geographic regions
- Most trends in agricultural are positive showing a fast increase in productivity
- Here, it has not been possible to go into a detailed analysis of the sustainability of current trends in agriculture and forestry
- Overall trends taken together suggest huge potential for improvement through, e.g. a better distribution of resources increasing yields in Africa and increasing efficiency in use of fertilisers in Asia.

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Chapter 5
Energy Resources and Regional Balances

Erik Dahlquist

5.1 Global Overview of Energy Resources and Conversion Capacity

In 2011, the total electricity production breakdown was: renewables 4 400 TWh (4,39766E + 12 kWh), nuclear 2 580 TWh (2,58368E + 12 kWh), hydro electric 3 470 TWh (3,46712E + 12 kWh), natural gas 4 850 TWh(4,84773E + 12 kWh) and coal 9 130 TWh (9,13062E + 12 kWh). In 2011, 81% of all primary energy globally was from fossil fuels.

Renewables and waste were 9.8% of the total primary energy globally. In 2006, this corresponded to 1 184 909 tonne.

In Fig. 5.1, we see how the pump price for gasoline varies between different regions. Here, we see that the price is approximately two times as high in the EU compared to Russia, but also a strong increase generally between 2002 and 2012. During this period the raw oil spot price at the market was around 100 US$/barrel. During 2014–2016 the price then dropped to approximately 30 US$/bl at the beginning of 2016, but then started to increase a little again and is around 50 US$/bl. Many oil producing countries have used the income from oil to finance their overall budget, although some countries like Norway have invested the oil money in buying shares in international corporations. Due to this dependency on oil, countries like Russia, Nigeria and others have run into problems with national economy. As Iran reenters the oil market after the trade embargo, more oil comes to the market than there is demand, which of course influences the oil price. Saudi-Arabia probably wants to keep the oil price a bit lower to counter that the US and Canada produce oil and gas using fracking and oil tar sand respectively.

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Springer International Publishing AG 2017
E. Dahlquist, S. Hellstrand (eds.), *Natural Resources Available Today and in the Future*, DOI 10.1007/978-3-319-54263-8_5

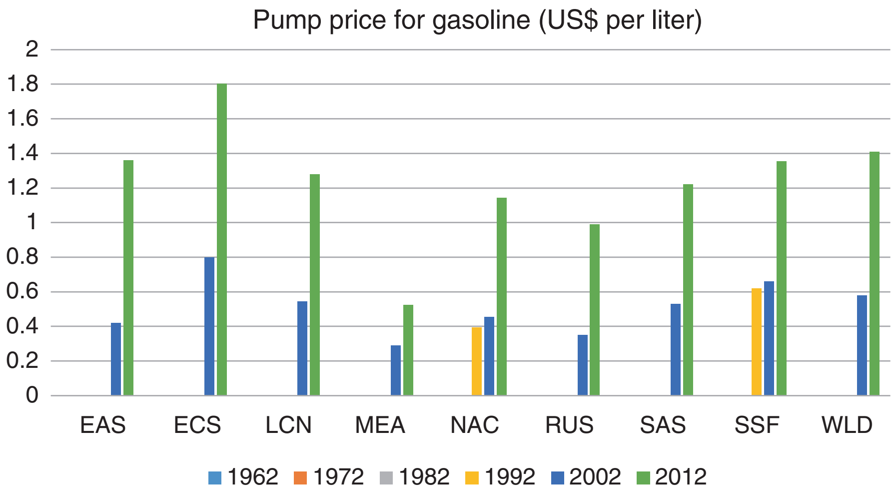


Fig. 5.1 Pump price for gasoline in US$/liter 1992–2012 in different regions

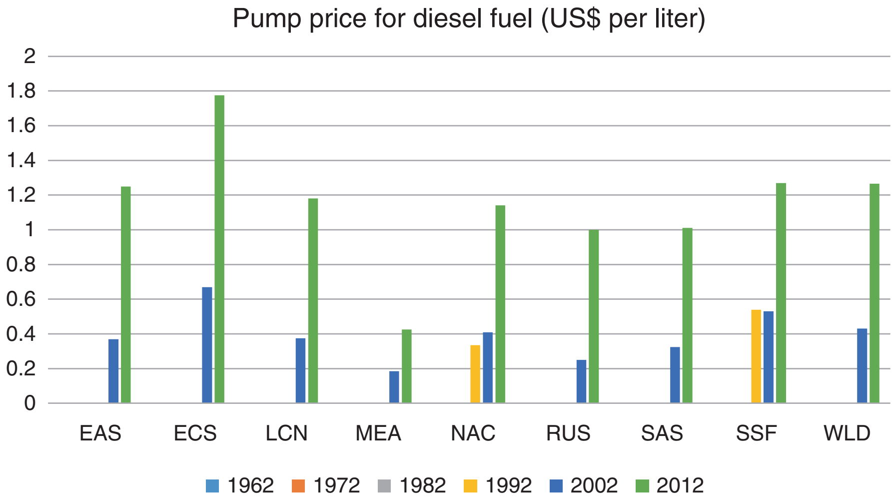


Fig. 5.2 Price for diesel per liter in US$/liter in different regions

In Fig. 5.2 we see the corresponding price for diesel. Here, we can see that the price today is almost the same as for gasoline.

In Fig. 5.3 we see the percentage of all energy used that comes from fossil fuels in different regions. Here, we can see that the percentage decreases in Europe and North America while it increases in East Asia and very strongly in South Asia (India mostly).

In Fig. 5.4 we see the energy use given as kg oil equivalents per capita in different regions. North America is several times higher than the average. In the EU, the

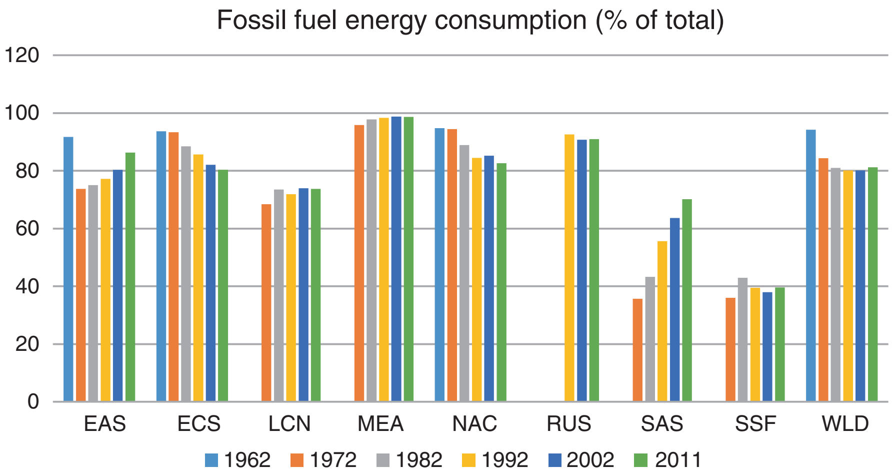


Fig. 5.3 Fossil fuel energy consumption as % of total energy consumption in different regions

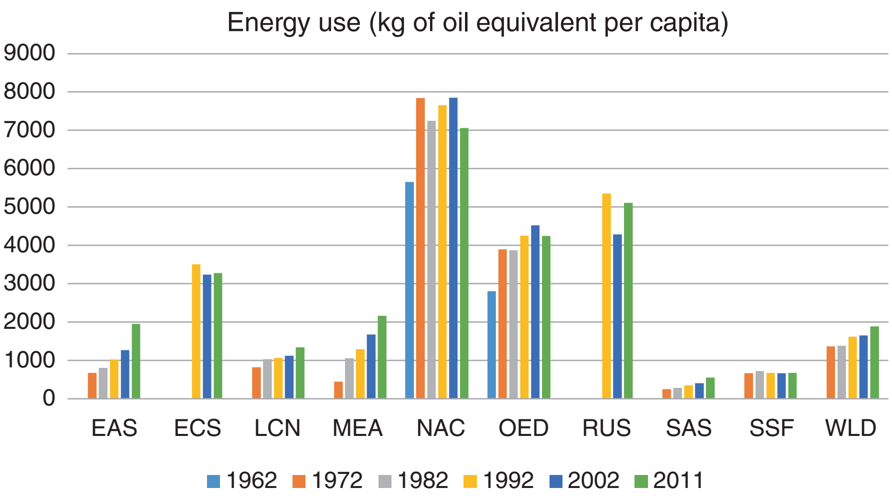


Fig. 5.4 Energy use per capita as kg oil equivalents (oe)

deviation is significant between different countries, and in China the increase has been significant over the last few decades due to the strong development of industry production. To some extent the figures are misleading as countries with a high amount of energy intensive industries get high values, although the products are sold in other countries and regions. If we look at counties instead this is seen even stronger.

In Fig. 5.5 we see how much of the electricity was produced from renewables 1962–2011 excluding hydro power, which is renewable but also seen as “conventional”. It is interesting to see the dramatic increase in most regions during the last

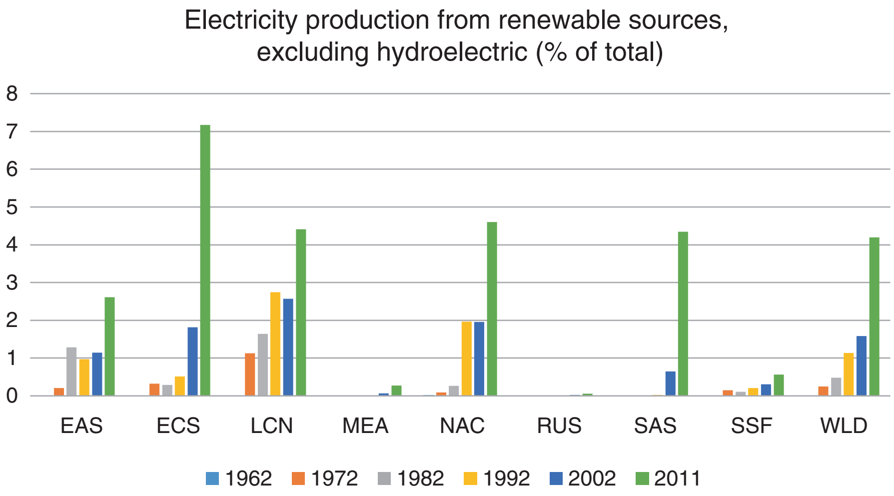


Fig. 5.5 Electricity production from renewables excluding hydro power in percent of total

few decades. The trend is also proceeding, although the figures are not in the World Bank data set yet. In a country like Germany, the installed capacity of solar power (PV) was 35 000 MW 2015 and more than 40 000 MW wind power. In Sweden and Brazil, the amount of biomass is higher than the amount of fossil fuels as the primary energy source. Different countries focus on what is suitable there, and thus we see solar power in some, wind in others and biomass in those with a lot of biomass. As a complement, we have hydro power, which produces 98% of all electric power in oil-producing Norway! They use hydro power for their own demands and export the oil and gas to other countries. We also see that both Norway and Sweden use the large amounts of hydro power to balance more unreliable sources like wind and solar power in the rest of Northern Europe with Germany, Denmark, Poland, Finland and the Netherlands.

In Fig. 5.6 we see the absolute figures for electricity production in kWh; 10^{-12} kWh is 1000 TWh. We can see that East Asia, the EU and North America all produce around 1000 TWh/y from renewable sources including hydro power. Since, South America also has a very high capacity of hydro power, they produce almost the same amount! The total capacity from renewables is more than 4 000 TWh_{el}/y, or 20–25% of the total electric power production globally. It is noteworthy that it has increased from around 500 TWh/y in 1962 to 4300 TWh/ in 2011, and the trend continues.

In Fig. 5.7 we see the development of hydro power in % of total. Since the total has greatly increased, the figures show more that the development has been equal to the one using fossil fuels in most regions (Europe, Latin America, Russia and Africa south of Sahara) except in North America, China and India, where other sources, mostly fossil, have expanded while hydro power has not. In the Middle East and North Africa this is even more significant, where expansion using fossil fuels has been very high.

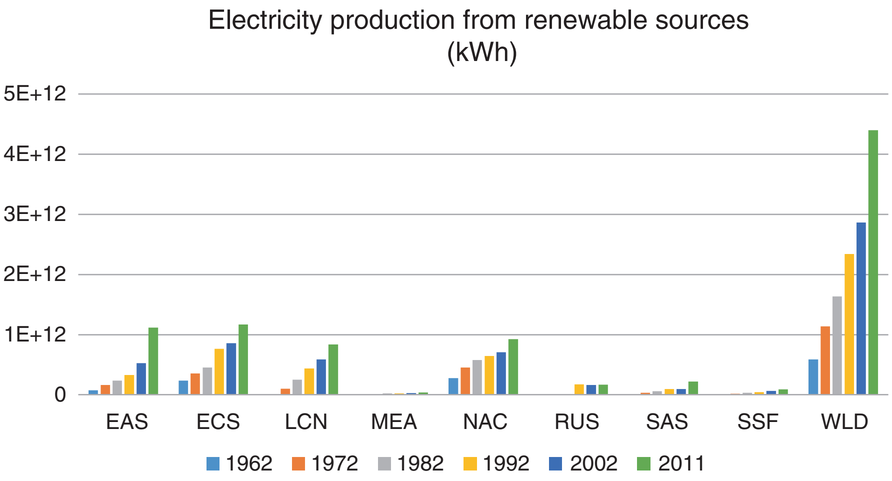


Fig. 5.6 Electricity production from renewable sources including hydro power in different regions

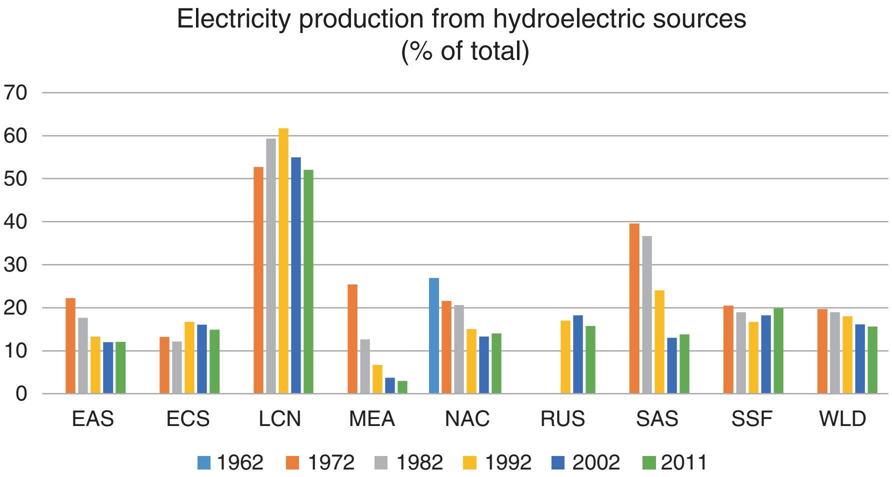


Fig. 5.7 Electricity production from hydro power in % of total in different regions

If we also include nuclear power alongside other renewable sources we get the total non-fossil production. In Fig. 5.8 we see the percentage of these in relation to total energy use. The value 13–14% in the EU and North America reflects that approximately 50% of the electricity is actually produced without using fossil fuels, but a lot of other energy demands like transportation still utilize fossil fuels.

In Fig. 5.9 we see the nuclear electricity production for different regions. What we can see is that nuclear power is of significant importance in the EU and North America, and to some extent also in East Asia, but less important in most regions.

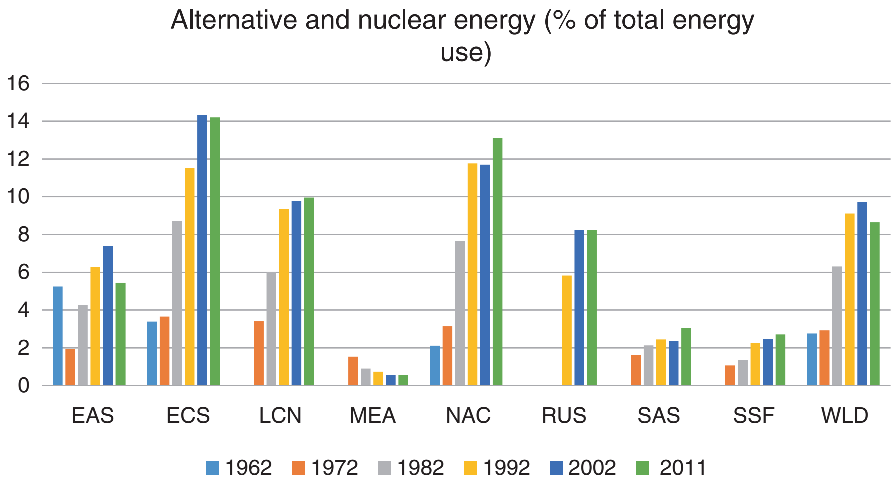


Fig. 5.8 Alternative and nuclear energy in percentage of total energy use in different regions

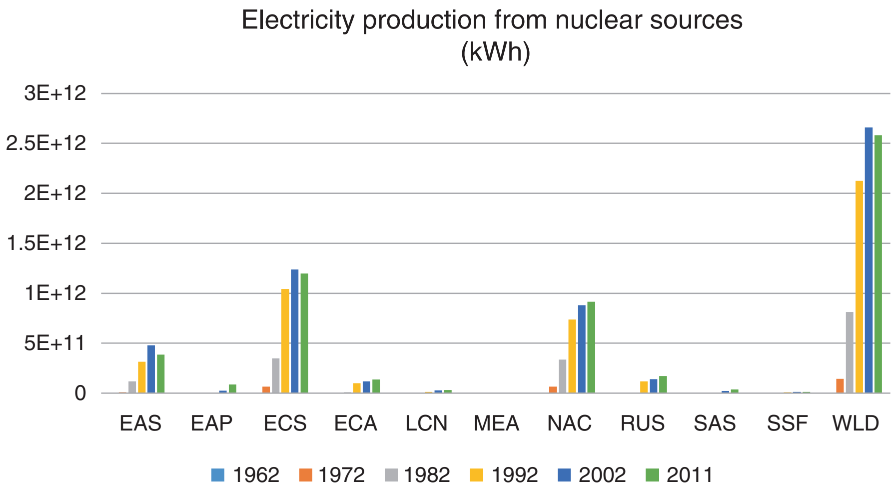


Fig. 5.9 Electricity production in kWh/y using nuclear sources in different regions (10^{12} kWh is 1000 TWh)

In Fig. 5.10 we can see that the total electricity production is approximately 23 000 TWh/y, which can be compared to the total production of non-fossil electricity which was some 7 300 TWh/y (31.5% of total electricity produced). The fossil driven electricity production was 66.8% of the total; where, 40.3% is coal, 22.4% natural gas and 4.1% oil. This data is for 2012 from World Bank Development Indicators.

If we look at the total amount of renewable energy (~7300 TWh/y) from electricity production, and include biomass we can add some 10% of the total energy used

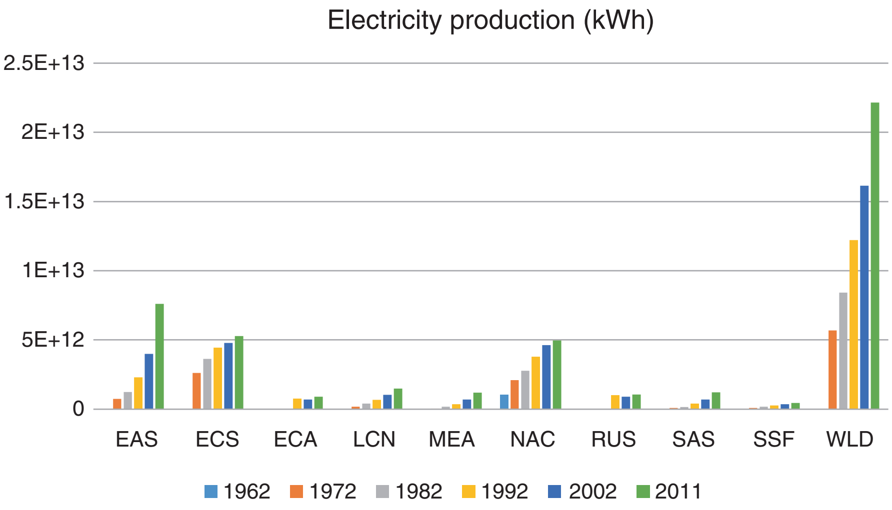


Fig. 5.10 The global electricity production distributed to regions. 10^{13} kWh = 10 000 TWh/y

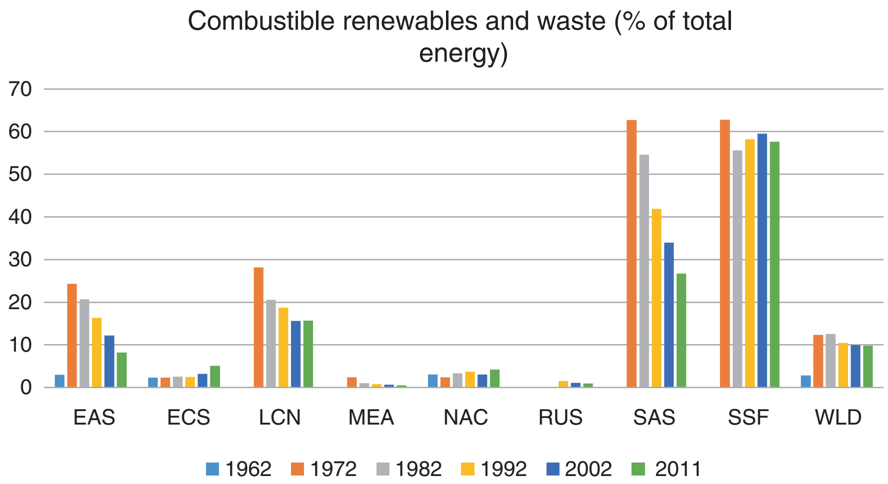


Fig. 5.11 Combustible renewables and waste in % of total energy used globally

as seen in Fig. 5.11. These 10% correspond to some 13 000–14 000 TWh/y, and the total percentage of non-fossil energy used is thus some 15%, including nuclear and hydro power.

We now can look at the distribution of electricity (Fig. 5.12) and total energy (Fig. 5.13) for countries with different average income levels as seen in Table 5.1.

The first thing we can see is that all income groups, except low income countries (LIC), have had a fast development of electricity production.

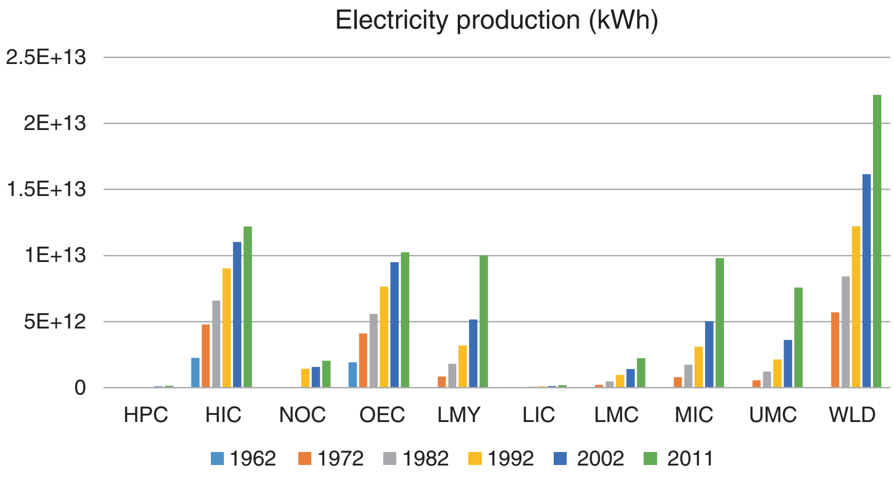


Fig. 5.12 Electricity production distributed based on countries with different income levels (kWh/y)

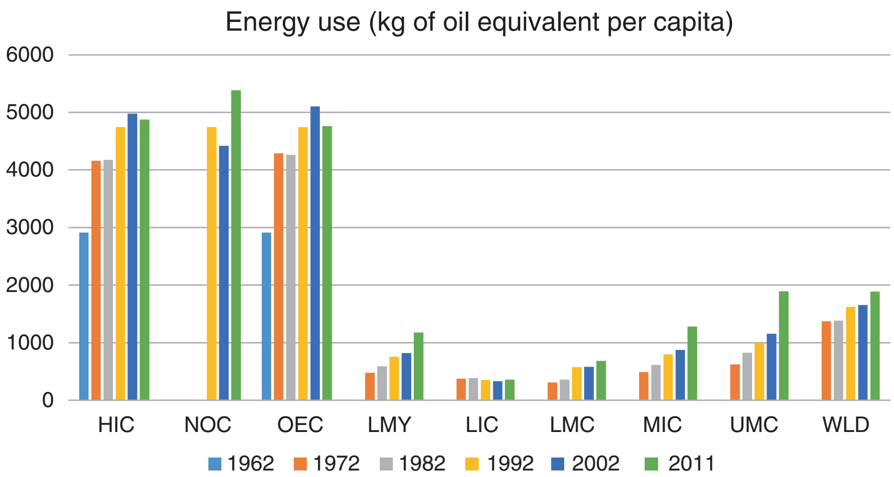


Fig. 5.13 Kg oil equivalents used per capita in different income level countries

Total energy use has not developed in the same way. It is primarily upper-middle income (UMC) and middle income (MIC) countries where energy use has increased most over the last few decades (Fig. 5.13).

This could be explained with the fact that electricity consumption is more correlated to economic development than energy as such. For some rich countries we even see a lowered energy use during the last 10 years due to energy conservation measures.

Table 5.1 Different income categories

Heavily indebted poor countries (HIPC)	HPC
High income	HIC
High income: nonOECD	NOC
High income: OECD	OEC
Low & middle income	LMY
Low income	LIC
Lower middle income	LMC
Middle income	MIC
Upper middle income	UMC
World	WLD

5.2 Renewable Energy: Wind Power and Solar Power

We have already mentioned that renewable energy is strongly increasing. What is meant by renewable energy in the statistics is usually wind and solar power, while biomass and waste are presented separately.

5.2.1 Wind Power

The total global installed wind power capacity was 318 105 MW in 2013; from this 121 474 MW was in Europe, 115 927 MW in Asia and 70 811 MW in North America.

Fig. 5.14 shows the installed capacity of wind power globally in 2013.

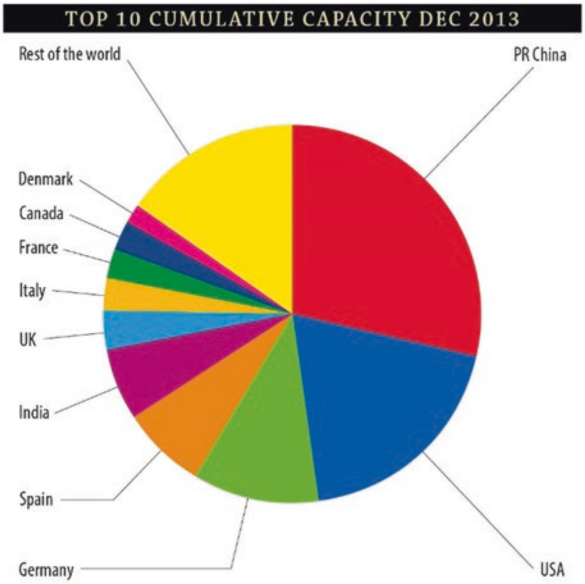
A few years ago, Germany dominated installations but was passed by China in 2013 with 16 088 MW new capacity, and a strong increase in India is also noteworthy.

In Table 5.2, we see both the total capacity in different countries and the new capacity in 2013.

We can see that China has the highest installed capacity for a single country with 91 GW, while the US is close with 61 GW. Germany with 35 GW, Spain with 23 GW and India with 20 GW also produce a lot of wind power. The total installed capacity was 318 GW 2013, and has increased to some 350 GW in 2016 (Fig. 5.15).

5.2.2 Solar Power, PV

We have seen a tremendous increase in solar power installed capacity over the last 10 years. The driving force has been the feed-in tariff in Germany, where there was 35.5 GW installed capacity in 2013. In 2010 the capacity increase was 9.8 GW, and in 2010–2012 additional capacity was 6 GW per year. Aside from the feed-in tariff



Country	MW	% SHARE
PR China	91,412	28.7
USA	61,091	19.2
Germany	34,250	10.8
Spain	22,959	7.2
India	20,150	6.3
UK	10,531	3.3
Italy	8,552	2.7
France	8,254	2.6
Canada	7,803	2.5
Denmark	4,772	1.5
Rest of the world	48,332	15.2
Total TOP 10	**269,773**	**84.8**
World Total	**318,105**	**100.0**

Source: GWEC

Fig. 5.14 Installed capacity in 2013 of wind power globally

there were also ways to finance new installations, and a number of skilled PV-installation companies to support installations. However, the PV cells were mostly imported from China, and the biggest domestic PV cell producer, Q-cell, went bankrupt. They have started up again but now in a smaller scale and with international partners. Germany currently has 26% of global installed capacity.

China had 18.3 GW installed capacity in 2013, and is the second biggest. In 2010, China only had 0.3 GW installed, so we can see that the increase was very fast, and they are expected to pass Germany within a few years. Especially, since the installed capacity has slowed down. The target in China is to have 70 GW PV cell capacity installed by 2017, as they want to reduce the demand for new coal power capacity due to the severe climatic and environmental issues in many Chinese cities.

Table 5.2 Total installed and new capacity of wind power for 2013

Global Installed Wind Power Capacity (Mw) – Regional Distribution				
		End 2012	New 2013	Total (End of 2013)
Africa & Middle East	Ethiopia	81	90	171
	Egypt	550	–	550
	Morocco	291	–	291
	Tunisia	104	–	104
	Iran	91	–	91
	Cape Verde	24	–	24
	Other (1)	24	–	24
	Total	**1 165**	**90**	**1 255**
Asia	PR China	75 324	16 088	91 412
	India	18 421	1 729	20 150
	Japan	2 614	50	2 661
	Taiwan	571	43	614
	South Korea	483	79	561
	Thailand	112	111	223
	Pakistan	56	50	106
	Sri Lanka	63	–	63
	Mongolia	–	50	50
	Other (2)	71	16	87
	Total	**97 715**	**18 216**	**115 927**
Europe	Germany	31 270	3 238	34 250
	Spain	22 784	175	22 959
	UK	8 649	1 883	10 531
	Italy	8 118	444	8 552
	France	7 623	631	8 254
	Denmark	4 162	657	4 772
	Portugal	4 529	196	4 724
	Sweden	3 746	724	4 470
	Poland	2 496	894	3 390
	Turkey	2 312	646	2 959
	Netherlands	2 391	303	2 693
	Romania	1 905	695	2 600
	Ireland	1 749	288	2 037
	Greece	1 749	116	1 865
	Austria	1 378	308	1 684
	Rest of Europe (3)	4 956	832	5 737
	Total Europe	**109 817**	**12 031**	**121 474**
	of which EU-28 (4)	106 454	11 159	117 289

(continued)

Table 5.2 (continued)

Global Installed Wind Power Capacity (Mw) – Regional Distribution				
		End 2012	New 2013	Total (End of 2013)
Latin America & Caribbean	[a]Brazila	2 508	953	3 461
	Chile	205	130	335
	Argentina	142	76	218
	Costa Rica	148	–	148
	Nicaragua	146	–	146
	Honduras	102	–	102
	Dominican Republic	33	52	85
	Uruguay	56	4	59
	Carribean (5)	136	–	136
	Others (6)	54	20	74
	Total	**3 530**	**1 235**	**4 764**
North America	USA	60 007	1 084	61 091
	Canada	6 204	1 599	7 803
	Mexico	1 537	380	1 917
	Total	**67 748**	**3 063**	**70 811**
Pacific Region	Australia	2 584	655	3 239
	New Zealand	623	–	623
	Pacific Islands	12	–	12
	Total	**3 219**	**655**	**3 874**
	World total	**283 194**	**35 289**	**318 105**

[1]Israel, Jordan, Kenya, Libya, Nigeria, South Africa
[2]Bangladesh, Philippines, Vietnam
[3]Bulgaria, Cyprus, Czech Republic, Estonia, Finland, Faroe Islands, FYROM, Hungary, Iceland, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Norway, Romania, Russia, Switzerland, Slovakia, Slovenia, Ukraine
[4]Austria, Belgium, Bulgaria, Cyprus, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, UK
[5]Caribbean: Aruba, Bonaire, Curacao, Cuba, Dominica, Guadalupe, Jamaica, Martinique, Granada
[6]Bolivia, Colombia, Ecuador, Peru, Venezuela
Note:
[a]Projects fully commissioned, grid connections pending in some cases
Project decommissioning of approximately 374 MW and rounding affect the final sums

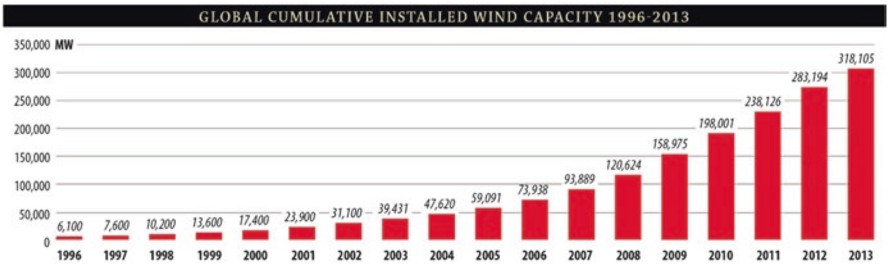


Fig. 5.15 The global installed capacity of wind power from 1996 to 2013

Italy had almost as much PV installed in 2013, with 17.6 GW, which is a significant increase from 2010 when they only had 1.2 GW. At 17.6 GW Italy had the highest percentage of electric power produced from PV with 7.8%, compared to 6.2% in Germany. In Italy, there are both feed-in tariffs and net-metering that is not taxed if you use the power internally. In combination with a lot of sunshine this has been very successful for stimulating expansion.

Japan also has a significant amount of solar power with 13.6 GW installed in 2013 and 2.6 GW in 2010. Government residential PV programs, net-metering, high national solar energy goals to reach 28 GW by 2020 and 53 GW by 2030 as well as the support of local authorities and the private sector has stimulated the expansion. The Fukushima reactor melt-down has stimulated replacement of nuclear power as well. A plan now is to build floating solar farms as well.

The first PV cells were developed in the US. In 2010, they had 1.6 GW installed and in 2013 12 GW. New business models have been implemented in, e.g. California, where power companies install PV plants in residential buildings and the inhabitants pay for only produced power without having to pay for the actual installation. This has driven the expansion, and the strongly reduced PV cell cost over the last few years has made it even more interesting.

Other countries who have installed large areas of PV cells are Spain with 5.6 GW, France 4.6 GW, Australia 3.3 GW, Belgium 3 GW, UK 2.9 GW and India 2.3 GW.

As the price per m^2 has dropped to less than half and the efficiency almost doubled over the last 5–10 years, PV systems now are economic even without large subsidies, compared to alternatives like nuclear power. Still, there must be a demand for new capacity and the alternative to save energy is normally the most economic.

5.2.3 Biomass Conversion

System aspects of biomass use in complex applications include bio-refineries for production of heat, electric power and chemicals like fuels for vehicles, clothes etc. such that different conversion processes are important. This includes production of bio-diesel by mixing fatty acids with methanol, biogas production from waste and high temperature gasification for production of hydrogen, methane and carbon monoxide, which can be used directly or reacted further. Torrefaction for production of biochar and pyrolysis for production of organic liquids and biochar are other processes. Ethanol production using saccharomyces or bacteria are other routes, where biorefineries usually take these processes a step further.

Today we can see that biomass resources are primarily used as food, for cooking food, for heating buildings and in forest industry applications. In the future, we can expect that these applications will be developed further to replace routes for production of all the chemicals produced today from fossil fuels like oil. As oil becomes scarce and probably more expensive, use of biomass instead will be attractive. As Newsprints and fine papers are replaced by electronic media we see a trend to stop producing these qualities, and cellulosic raw material becomes available for other products. Today, tissue is increasing as well as packaging, but also replacement in cloth production of wool is increasing as an environmentally friendly alternative. All kinds of lignin components are also used for production of chemicals for paint, tensides, bio-diesel, tall oil for combustion etc.

The focus of this book is not the biomass conversion but more to look at the resources as such. For those who are interested, a number of articles for deeper study are proposed in the reference list below, and the titles are self-explanatory.

5.3 Energy Situation in Different Countries and Regions

The available energy resources are very different in different countries and regions. In Russia, there are enormous amounts of forestry wood; in China straw from agriculture; in Norway potential for wave power. Along most coasts the potential for wind is high. Solar power is interesting in many countries, but especially in regions around the Mediterranean Sea and in dessert areas like in Arizona.

5.3.1 EU27 Energy Situation 2014 and Onwards

Available *biomass* resources in the EU are in the range of 8 500–12 500 TWh/y for the EU27. The first figure comes from multiplying all arable areas with 10 ton DS/ha, and all forest areas by 3 ton DS/ha, and assuming 5.2 MWh/ton DS as heating value. The second figure is an estimated potential if we use specific species with high yield and optimize production with respect to irrigation and fertilizers.

Wind power today produces some 100 TWh/y in the EU27 but with a potential for at least 1000 TWh/y. The major potential is in the coastal areas, where both wind speed and time when windy is best.

Solar power potential could produce some 200 TWh/y within some 20 years, if the expansion was the same across the entire EU as it has been the last few years in Germany. However, even with the price dramatically decreased over the last 5 years, it is still relatively high. Tax regulations and subsidies will be important for the penetration, and the regulatory system generally still does not favour renewables and biomass use.

Hydro power makes up 10.2% of the total electric power produced in the EU27 today. This corresponds to 350 TWh/y as the total production is approximately 3400 TWh/.

Nuclear accounts for 29.5% of all electric power produced in the EU27 or 1000 TWh/y. The debate on if we should proceed with nuclear power or not is intense in several countries, where France and Finland are very positive towards building new nuclear plants, while Germany and Sweden do not want "competing power" by nuclear. The tax profitability has been poor in both countries, and thus there is not motivation for new capacity, especially where old units are closed for economic reasons.

Table 5.3 Installed capacity as % of total electric power (GW) as well as the share in electric energy (TWh/y) for each separate energy conversion technique in the EU27 at the end of 2010 by Eurostat

	% of 850 GW	% of 3400 TWh/y	
Oil 55 GW	(56%)	55.2	Fossil 55–56%
Coal 231 GW			
NG 212 GW			
			Non-fossil 44–45%
Nuclear 127 GW	(15%)	29.5	
Large hydro 121 GW	(14%)	10.2	
Small hydro 5 GW	(1%)		
Wind 85 GW	(10%)	2.4	
PV 25 GW	(3%)	< 1%	
Biomass 6 GW	(1%)	2.7	
Waste 4 GW	(0%)		
Peat 2 GW	(0%)		
Geothermal 1.5 GW	(0%)		
CSP 0.5 GW	(0%)		
Tidal and wave 0.25 GW	(0%)		

If we accept nuclear as a non-fossil resource the *available resources* would be (8500–12 500)bio + (100–1000)wind + (5–200)solar +350hydro + 1000 nuclear **=9 955–15 050 TWh/y** (Table 5.3).

The following section covers some important regions a bit more in detail. Especially, the official figures are presented together with my own estimates for the total production, and not only the "valuable parts" that are traded. The overview does not cover all countries and regions, but represents approximately half of the population on earth, and most types of climate zones.

5.3.2 EU27: An Overall Energy Balance

I have made some calculation of the agricultural and forestry production with respect to bioenergy for the EU27 (the EU with 27 member countries). The conservative figures Dahlquist et al (2012) say the annual growth of biomass is around 8 500 TWh/y, which can be compared to the 16 000 TWh/y primary energy used today according to official figures. With reasonable improvements in the growth rate due to selection of crops with higher yields, improved irrigation and addition of nutrients, the production of biomass in the EU region could possibly reach 12 500 TWh/y. By implementing energy efficiency improvements in transportation, buildings and industry it should be possible to reduce the need for primary energy to around 12 500 TWh/y. Together with hydro power, solar power and wind power the balance between available renewable resources and consumption should be possible to reach without the need for fossil fuels.

Fig. 5.16 Typical cereal agricultural land in Northern Europe (Nibble farm, Vasteras. Photo E. Dahlquist)

In Europe, cereals like wheat are the most important crop. A typical view of farmland for cereals is seen in Fig. 5.16. In this case we see a field with spring wheat as well as autumn wheat.

5.3.3 China: Today and in the Year 2050

The Chinese Academy of Engineering has made predictions for the energy utilization in China until the year 2050 (Du Xiangwan 2008). The prediction is that renewable energies should deliver 0.88–1.71 billion tce 2050 (tce = ton coal equivalent, approximately 7.4 MWh), reaching a 17–34% share of the national total demand. Including hydropower the renewables will give 1.32–2.15 billion tce providing 26–43% of the national total energy demand. Assuming the 1.7 billion tce total renewables in 2050, 26% will come from hydro-power, 20% from biomass, 34% from solar power and 18% from wind power. Other renewable energies will contribute 2% in this scenario, where the total utilization is predicted to be five billion tce 2050. The production of bio pellets and briquettes will increase to 50 million tons by 2050. The increase of electric power from biogas fueled power plants will be 20 GW by 2020 and 40 GW by 2030. Some of this will be through co-firing of biomass in coal fired power plants. Also, CHP will most probably increase to enhance the total efficiency for both coal and biomass fuels. Only 200 MW of electric power was installed in 2006 using biomass fuels, but the capacity is increasing fast.

There are already more than 22 million small scale biogas plants producing 8.5 billion Nm3/y. Medium and large scale biogas projects will increase from 3671 year 2007 producing two billion Nm^3/y biogas to 44 billion m^3 by 2020 and 80 billion m^3 by 2030 (the figure in 2006 was 10 billion m^3 per year) according to Professor Li Shi-Zhong at Tsinghua University (2011). Also, 39 million tons of bioethanol and six million tons of bio-diesel were produced in 2007.

China has about 120 million hectares of marginal land and 40 million hectares of degraded arable land. Tuber crops have high biomass production yield (15–45 t/ha) and starch content (20–33%). Cassava is a good crop in southern China as it is less sensitive to diseases and insects, resistance to drought etc. Sweet potato can also be planted in poor quality soil.

There are about 16 million ha of marginal land available for planting starch tuber crops like cassava and sweet potato (Subramanian Narayana Moorthy).

High ethanol yield has been achieved: 4.7 m^3/ha for sweet sorghum stalk vs. 3.7 m^3/ha for corn and 3.8 m^3/ha for sugarcane. This can be compared to 1.5 m^3/ha for sweet sorghum grains and 4.8 for bagasse. Straw from agricultural crops results in 600–700 million tons of agricultural waste in China annually; 1.7 million tons of livestock and fowl's manure is produced annually from the breeding industry in China as well. The most important food crops in China are wheat in the north with a total of 114.5 million tons produced in 2009, and rice in the south with 197 million tons produced the same year.

5.3.4 India

In India, rice is the most important food crop (99.2 million ton/y) followed by wheat (80.6 million ton /year 2009). The productivity of wheat varies a lot between different states, from 0.7 to 4.3 ton/ha,y. Coarse cereals give 39.5 million ton/y and pulses 14.7 million ton /y. This gives 233.9 million ton/y (2009) of all major crops altogether. Singh (2010) at the National Directorate of Wheat Research in India states that wheat makes up ~50% of the caloric intake of the Indian population. The productivity with respect to wheat has increased from 0.9 tons/ha in 1965 to 3 tons/ha,y today on an average. The increase has been due to selection of suitable clones for each type of soil and other conditions. This, of course, is very promising. The highest yields are in Punjab and Haryana with 4–4.3 tons/ha,y, while Karnataka has only 0.7 tons/ha,y. This shows that there is still potential for improvements. Today, the production is 67 kg/capita, while the demand is 73 kg/capita. It is believed with further improvements there will be a balance within 10 years. Rusts, leaf blight, insects as well as climatic issues are still potential threats. There is almost the same amount of biomass production available as straw, 240 million tons. Altogether, this means some 480 million tons of biomass from these crops with a HHV of 480 *106 *5.4 MWh/ton =2 600 TWh/y. Still, this is just a minor share of the total biomass available.

5.3.5 USA

Georg Huber and Bruce Dale (Scientific American, July 2009) made a review of US biomass potential especially for the purpose of fuels for vehicles. The authors presented the following figures for the US: 428 million tons agricultural waste, 377 million tons Energy crops, 368 million tons forest products, 87 million tons corn and other grains and 106 million tons other types of organic residues. Totally, this gives 1366 million tons/year of crop residues. They also discuss possible energy crops as a complement, where the following are considered to be of highest interest in the US: ewitchgrass, sorghum, miscanthus and energy cane. The authors estimate that these residues and crops could produce 3.5 billion barrels of oil equivalents, which is roughly 50% of the 7.1 billion barrels of oil used today in the US. If we make an assumption that these crops have a HHV of 5.4 MWh/ton, it means 7376 TWh/y. In many areas in the western US we see relatively arid biotopes.

We can also make another calculation to estimate the bioenergy potential in the US. From World Bank indicators (2011) we see that the average cereal yield is 7.2 tons/ha in the US. The agricultural area is 58 001 425 ha, giving 4.4 *108 ton/year, or with 5.4 MWh/ton = 2270 TWh/y additional as cereals. This is 14% of the total agricultural land, 411 200 000 ha. If we assume the same amount of straw is produced, that is 2270 TWh/y, we get 4540 TWh/y from cereals including straw, and if we get the same amount of production on the rest of the land with energy crops, it would be 4540/0.14 = 32 430 TWh/y.

The most widely grown crop in the US is corn with 332 million tons per year. From this figure 130 million tons or 40% is used for production of ethanol fuel. To decrease the political risks with oil import, the US government stimulated ethanol production by paying a guaranteed price per liter ethanol. There is no request on how the ethanol is produced, and thus oil and coal is often used to produce and distil the ethanol, giving a poor ratio between the heating values of ethanol produced in relation to fossil fuels used for the production. This is the major reason for claims that ethanol is bad for the environment heard especially in the European mass media.

The forest land area is 304 022 000 ha. If we assume an average of 3 ton DS/ha,y or 16 MWh/ha, we should produce some 4 900 TWh/y from this as well. A total production then would be approximately 37 350 TWh/y in the US. In (Ronald S. Zalesny, Richard B. Hall, Jill A. Zalesny, Bernard G. McMahon, William E. Berguson, Glen R. Stanosz, BioEnergy Research, 2009) the growth rate of different clones of hybrid poplar was evaluated. The average of 10 clones at 10 sites was approximately 11 ton DS/ha,y. If we assume 30% of the US forest land area is planted with this it would mean 304 022 000 ha * 0.3 * 5.4 MWh/ton* 11 ton/ha,y = 5 420 TWh/y and a total of 5420 + 4 900*0.7 = 8 850 TWh/y.

If we compare this to the total use of energy in the US this is 4160 TWh/y electricity and 2 172 107 kton of oil equivalents/y, or with 10 MWh/ton o.e. 21 720 TWh/y totally (from which fossil fuels is 84% today). These figures show that the available biomass resources should be enough to cover all energy needs if used efficiently. The US government has stated that by 2030 biofuels will have replaced 30% of fossil fuels. An obstacle for this to happen is the strong push from the oil industry to do fracking, where explosives are used in oil and gas containing soils, to get the gas out. This has been very popular alongside extracting oil from oil tar sand, especially in Canada. The big drawbacks are environmental issues as well as high costs, especially for the oil tar sand production.

The conditions for biomass production to cover "own needs" in Canada are principally even better than in the US, while Mexico has more limitations for biomass production due to drier climate.

5.3.6 Brazil

Brazil is generally a very "green" country with a lot of forests and farm land areas. Since the 1980s, Brazil has been a leading country with respect to production of bio-ethanol for vehicles. First, there were many cars running on ethanol during the 1980s. Then oil became more favourable due to new political decisions and regulatory rules. Since the beginning of the new millennium, ethanol has taken back its position as a dominating car fuel. Thus, Brazil is now the major producer of ethanol globally alongside the US.

There have been a lot of discussions about environmental issues around the ethanol production in, among others, Brazil. It has been claimed that rain forests have been cut down to plant sugar cane, where the sugar is fermented to ethanol, and the bagasse used for the distillation of the ethanol. In reality this is not correct, as sugar cane normally is grown at land areas with a different climate, further to the south of Amazonas. Instead soya beans are planted where rain forests are cut down. The Soybean powder is then, to a large extent, exported to western animal farms for production of the meat we eat.

Carlos H. de Brito Cruz writes in the report "Bioethanol in Brazil. 2008" that 15% of all energy used in Brazil is sugar cane. In 1988, 50% of all vehicle fuel was ethanol; in 2004 it was 30%. Sugar cane gives 6 m^3 ethanol/ha. The total arable land in Brazil was 354.8 million ha in 2007. From this, 76.7 million ha were used for crops: 20.6 for soybean, 14.0 for corn, 7.8 for sugar cane. From this, 3.4 million ha were used for ethanol production. This corresponds to 1% of the arable land area, but replaces 30% of the fossil fuel used for vehicles. 172.3 million ha are pastures, and thus we have 105.8 million ha left for additional ethanol production. If we triple the production 11.3 million ha would be needed, or 7.9 million alongside what is already utilized. This would mean 7.5% of the available arable land not used intensively today. It is noteworthy that the cost for sugar cane ethanol production is 0.25 $/liter compared to 0.4–0.7 $/liter for fossil gasoline in Brazil, according to Carlos H. de Brito Cruz (2008).

Furtado et al (2011) has investigated the Brazilian sugar cane innovation system. What further developments can be made to make ethanol production even more economic? Also Goldemberg (2007) has studied development of ethanol production and Khatiwada et al has compared Brazil to Nepal concerning this, where Brazil is the good example to follow. Leite et al (2009) is even looking for the possibility that Brazil could replace a lot of fossil fuels even on a global scale with environmentally produced ethanol. Pousa et al (2011) is making a historical review of the development.

In ABRAF: Statistical Yearbook (2011) we can see data on Brazilian biomass resources. These are of high importance and approximately 35% of primary energy is actually from Biomass (EPE: BEN 2011). Baer (2008) was discussing the economic development which was strong before the economic crisis. This has been slowing down after 2008 significantly. Pulp and paper (BRACELPA, 2011) still is doing quite well. FAO (2003) has studied the development of forestry while Ferreira et al (2007) has investigated deforestation by sensing hotspots by remote sensors. Silveira (2005) has made a review of the potential for further development of the biomass resources. Nogueira et al (2007) also see biomass as a sutiable soruce for production of charcoal and Weidenmier et al (2012) have looked at the marcoeconomic impact of Brazil's alternative energy program, where etanol as a vehicle fuel is the most important part.

Yusuf et al (2011) also look at the biodiesl production, which is another alternative for bio-fuels for vehicles, while Gomez & Silveira (2010) have investigated the rural electrification, where also biomass play an important role.

5.3.7 Africa south of Sahara

Africa has many different climatic conditions, from very dry areas in the north to tropical and subtropical south of the Sahara. In the north, biomass has difficult conditions due to too little rain; while south of the Sahara the conditions are mainly quite good, especially in Western and Central Africa. In the very south, we see other areas with less rain, and thus difficult conditions for crops. This is especially true in Namibia, Botswana and parts of South Africa. The potential to use biomass for most needs is thus quite high in most countries south of the Sahara. The issue in many countries is the unstable political conditions causing problems in the development of both society and economy.

One interesting initiative to improve the productivity of African crops is the new species bred at the African Rice Center under the name "New Rices for Africa" (NERICA). Here, rice is selected to the tolerate harsh growing conditions and low nutrient levels.

In South Africa, we also have areas with conditions quite good for crops, and there are many wine yards in the region close to Stellenbosch and Cape Town.

5.3.8 Other Regions

There are many areas with poor conditions for agriculture where animal breeding may be an alternative. The amount of arable land globally is distributed in the following way for the largest countries: USA 179 000 ha, India 169 700 ha, China 135

557 ha, Russia 126 820 ha, Brazil 65 200 ha, Australia 50 600 ha, Canada 45 700 ha, Indonesia 33 546 ha, Ukraine 33 496 ha, Nigeria 30 850 ha, Mexico 27 300 ha, Argentina 27 200 ha, Turkey 26 672 ha, Pakistan 21 960, Kazakhstan 21 671 ha, France 19 582 ha, Spain 18 217 ha, Thailand 18 000 ha, Sudan 16 433 ha, South Africa 15 712 ha, Poland 14 330 ha and Germany 12 020 ha.

As can be seen, the distribution of arable land to some extent follows where we have a lot of people, e.g. India, China, Brazil and Indonesia, while some countries have huge surpluses in relation to their populations, e.g. the USA, Canada and Russia, especially Canada. In Australia, there is a lot of this type of land in the south eastern part. In a typical landscape of this there are some trees and much grass. At some places the rain is enough for more intense farming, while in other areas it is too little.

5.3.8.1 Global Perspectives

We should then also notice that the amount of straw is approximately the same as the grain that is harvested. So, the total biomass production that can be utilized in high income countries then is approximately 11 ton/ha,y. In forest areas, we can assume that the official production of approximately 2 ton DS/ha, y in reality is at least 3 tonDS/ha,y. In arable land we can assume slightly lower productivity and approximately 1.5–2 ton DS/ha, y can be reasonable figures to use. We also assume that the higher heating value (HHV) is 5.4 MWh/ton DS, which is a reasonable value.

We first take the official figures of land area for each group and multiply the cereal production in each group by 2. To this figure we add the total forest area times 3 t/ha,y and arable land multiplied by 2 t/ha,y, and multiply the total mass by 5.4 MWh/ton and we get:

Arable land with agriculture incl straw 187 000 TWh/y.
Forests 65 000 TWh/y.

Totally, this adds up to c 250 000 TWh/y as the higher heating value (HHV) of all the biomass produced on land. This can be compared to the total energy use of approximately 150 000 TWh/y globally. From this we can conclude that there is enough biomass energy for the global population if we use the energy in a good way. This means to first use wood for buildings, and then later use the waste wood for energy purposes. Use the grain of the plants as food, but also utilize the straw and other agricultural residues for first biogas or ethanol production, but also recycle the residues back to farm land areas as fertilizer etc.

It is also important to have sustainable farming and forestry that utilizes all resources in an effective way. Nutrients, for example, can be administrated in open soil during autumn or to growing crops during spring/summer. In the first case, a lot of the nutrients come out as leachate polluting waters or emissions to the air. In the second way, most of the nutrients will go into the crops instead. Administrating nutrients in a good way means lower amounts needed and less environmental impact, which is a win-win situation!

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Chapter 6
Nonorganic and Fossil Resources: Known and Estimated Resources

Erik Dahlquist

6.1 Metals

Metals are the most common elements and are used in many different applications, mostly in mechanics and electronics, but also as catalysts in chemical reactions.

Vernadsky institute in the former Soviet Union made a calculation of the composition of the earth's crust by averaging many thousands of sample analysis (Vernadsky, V.I.: Essays on Geochemistry, Book 1917). Later, Clarke and Washington (1924) from the US made a new estimate from 5159 samples. Others have followed up with new analysis, but these original ones still persist relatively well.

A very good review of the history of all elements was made by Per Enghag in three books (1998, 1999, 2000a, b). He has also gathered a lot of material about the use, resources available etc.

The web is also a good source for information, especially related to statistical data. Here, we can see values presented by the US government for a number of commercially important metals, while different mining organisations have made resource estimates relevant for their interests. Westcap in Massachusetts has made estimates for how much material made out of steel has been recycled in the US, but this has relevance for many other countries as well. At least iron, copper and aluminum are recycled to a very high percentage, but also many other metals are reused. Materials like calcium carbonate are difficult to recycle directly. Instead, concrete is reused in road buildings and similar. In the figures presented in this chapter, we still focus more on the virgin materials produced annually and what reserves we have and discuss how long the reserves will last at today's levels of usage. This is done primarily to give a rough figure of what materials are limited respectively and which are in reality not.

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E. Dahlquist, S. Hellstrand (eds.), *Natural Resources Available Today and in the Future*, DOI 10.1007/978-3-319-54263-8_6

6.1.1 Aluminum (Al)

Aluminum is considered to be the third most common metal element in the earth's crust. The aluminum used commercially is mostly in bauxite which exists in different forms like gibbsite, boehmite, and diaspore. Aluminum is also present in, e.g. clays, but extraction from this is normally not economically motivated today. After extraction of aluminum from bauxite, metallic aluminum is refined using electrolysis.

The content of Al is 82,000 ppm (=8.2%) in the earth's crust and $1–10 \times 10^{-4}$ ppm in the oceans.

Bauxite is mined in surface mines in China, eastern and southern Europe and Russia; here, we have 4–70 m deep layers, which makes it easy to mine.

Aluminum metals then are used in many different applications as the metal is very light compared to, e.g. iron. Aluminum metal is used in packaging, transportation, buildings, heat exchangers etc. Eighty-five percent of the aluminum is used as metals. Aluminum oxides are used for production of synthetic corundum, which is used for grinding, and in insulating materials like refractories.

6.1.2 Calcium (Ca)

Calcium is normally mined as $CaCO_3$, lime stone, chalk, calcite or marble. More than 4% of the earth's crust is Ca in different forms and it is relatively well spread over the world. The origin is normally shells that formed layers and then were transformed into rocks due to high pressure.

The content of Ca in the earth's crust is 41,000 ppm and in the oceans 400 ppm.

Due to this Ca is not a limited resource. The transfer of $CaCO_3$ into CaO emits huge amounts of CO_2 into the atmosphere and therefore increases global warming. http://www.ima-na.org/page/what_is_calcium_carb (Ca) (2016).

Calcium compounds are used as the main component alongside sand in concrete, in the pulp and paper industry to transform $NaCO_3$ into NaOH and reburn $CaCO_3$ to CaO, in combating acidification in agriculture, lakes and forests, as building material (e.g. marble), in blast furnaces when reducing iron oxides, in the oil industry as part of drilling fluid, in waste water treatment, as a filler in paper and plastics, and in ceramics.

6.1.3 Chromium (Cr)

Chromium is mostly used in steel alloys as an addition to iron, and normally also nickel (http://mineralseducationcoalition.org/mining-minerals-information/minerals-database/ (Cr) (2016). It is only present in the mineral chromite, and 99% of known resources are in only two areas, southern Africa and Zimbabwe. The estimated resources are 11 billion tons of mineable chromite globally, which would be enough for a few hundred years at the annual consumption of virgin Cr today.

The content in the earth's crust is 100 ppm and in the oceans 2×10^{-4} ppm.

When a high concentration of Cr is added to iron we get super alloys which can withstand most harsh environments like acids, salts and high temperature.

6.1.4 Cobalt (Co)

This material is quite scarce and is normally present in low concentration in, e.g. nickel ores. It is a magnetic material which makes it interesting in, e.g. permanent magnet engines. These have higher efficiency than normal motors or generators and are used in wind power plant generators. Cobalt alloys also are used in gas turbines and jet-engines.

Cobalt also gives a very beautiful dark blue pigment used in ceramics, pottery and tiles.

The major cobalt producing countries are Democratic Republic of the Congo, Zambia, Canada, Cuba, Australia and Russia, while the US consumes roughly 1/3 of all production.

The content of Co in the earth's crust is 20 ppm and in the oceans 3×10^{-6} ppm.

The estimated resources of Co globally are only 15 million tons. There may also be significant amounts at the sea bottom in manganese nodules, but for the time being the cost to mine these is too high. There may be millions of tons there.

Cobalt 60 is a radioactive element produced in nuclear reactors. This both causes problems when storing spent uranium fuel and is good to use in medicine as cobalt guns are used to fight cancer with gamma rays.

6.1.5 Copper (Cu)

Copper was the first metal used. Mixed with tin it forms bronze, which was very important several thousand years ago.

The content of copper is 50 ppm in the earth's crust and 10^{-4} ppm in the oceans (Fig. 6.1).

The use of copper is primarily in electric engineering applications like cables, where it is the conducting part. Copper also is a very resistant material and is thus used in, e.g. outer roofs in buildings, hot water piping, heat exchangers and other applications.

Estimates of how much minable copper there is indicate 1.6 billion tons. There are also nodules with magnesium, copper and other metals formed at the bottom of deep seas volcanoes. Some estimates indicate there could be 700 million tons here as well.

Chile is the major copper producer followed by the US and Peru, but other countries like Australia, Canada, China, Mexico, Russia and Indonesia can also be mentioned. Open mining at the surface is the most common mining method today.

Fig. 6.1 One of the oldest companies still active in the world is Stora Kopparberg with a mine in Falun, Sweden, for copper and iron. It has been in operation for at least 800 years

6.1.6 Gold (Au)

Gold is not a very important metal from an industrial perspective, but very important in the financial world. About half of the gold reserves are in South Africa, but also significant amounts exist in the U.S., Australia, Brazil, Canada, China and Russia.

The total amount of gold produced on earth so far is approximately 100,000 tons, which shows why the value per kg is very high.

As gold is very inert and a good conductor it is often used in electronic contacts in small quantities.

The content of Au in the earth's crust is 0.001–0.004 ppm and in the oceans 10^{-5} ppm.

6.1.7 Iron (Fe)

Iron is the most important metal for humans, and it has been used for thousands of years. Approximately 3000 years ago simple bloomery furnaces were developed in the region of Bergslagen north of lake Malaren in Sweden and approximately

900 years ago more or less industrial production started here using blast furnaces (Västmanland Archeology Board 2016). This was built on the principles from the bloomery furnace that had been used 3000 years ago in the region; which means to reduce iron ore, iron oxides, to metallic iron as a smelt. This then could be further refined and casted, and thereafter mechanically and heat treated. Later on, addition of other metals and carbon were made and thereby more advanced alloys were formed; but this was much later. The most important alloying elements are nickel and chromium, to make stainless steel, but also molybdenum is important to make acid resistant alloys (Figs. 6.2, 6.3 and 6.4).

The content of iron in the earth's crust is 41,000 ppm and in the oceans 10^{-4} ppm.

Iron (Fe) is the fourth most abundant element in the Earth's crust, 5.6% by weight. It is a metallic element. The principal iron ores contain hematite (Fe_2O_3) and magnetite (Fe_3O_4).

The annual production of iron is 3.2 billion metric tons of ore, with an average content of approximately 50% iron.

The world resources of economically extractable iron ore is more than 800 billion tons, with a metal content of approximately 230 billion tons of iron. Of course there is much more iron, but currently there is no economical motivation to mine.

If we look at the production of iron ore and the amount of known reserves of economically extractable ores we can see the figures in Table 6.1 [https://minerals.usgs.gov/minerals/pubs/commodity/iron_ore/mcs-2016-feore.pdf]

Fig. 6.2 Bog ore at Lapphyttan reconstruction site of old blast furnace from approximately year 1100 (Västmanland Archeology Board 2016)

Fig. 6.3 Old mine for iron production at Lapphyttan, Norberg, Sweden

Fig. 6.4 Reconstruction of blast furnace for Bog ore at Lapphyttan from approximately year 1100 (Västmanland Archeology Board 2016)

Table 6.1 World mine production and reserves (million metric tons/year)

	Mine production		Reserves (economic)	
	2014	2015e	Crude ore	Iron content
United States	56	43	11,500	3500
Australia	774	824	54,000	24,000
Brazil	411	428	23,000	12,000
Canada	44	39	6300	2300
China	1510	1380	23,000	7200
India	129	129	8100	5200
Iran	33	33	2700	1500
Kazakhstan	25	25	2500	900
Russia	102	112	25,000	14,000
South Africa	81	80	1000	650
Sweden	37	37	3500	2200
Ukraine	68	68	6500	2300
Other countries	153	125	18,000	9500
World total (rounded)	3420	3320	190,000	85,000

It is noticeable that the production in China is 1.3 billion tons while the iron content is only 17–20%, while the average of other ores globally is around 62% iron. This means that the Chinese figure corresponds to 325 million tons as 62% iron ore, which makes Australia and Brazil higher producers than China in reality.

Most of the iron used annually still is recycled iron. The virgin iron primarily fills up the increased wealth in previously poor countries which are now getting a higher share of materials and appliances. This includes cars and other vehicles, computers, mobile phones, containers, construction material in buildings etc.

A typical appliance is about 75% steel by weight and automobiles are about 65% steel and iron [https://en.wikipedia.org/wiki/Ferrous_metal_recycling] (2016). The overall recycling rate of steel in the US was 83% in 2008. For appliances it was 90% according to http://www.webcitation.org/5nge7f632 (2016). By recycling steel, 75% of the energy is saved in relation to using virgin iron. The global recycling rate was 88% in 2012, which is the highest recycling rate of all materials globally [http://www.steel.org/sustainability/steel-recycling.aspx].

Recycling one metric ton (1000 kg) of steel saves 1.1 metric tons of iron ore, 630 kg of coal, and 55 kg of limestone according to wastecap.org (2016).

6.1.8 Lithium (Li)

Lithium in batteries has become of great commercial interest over the last few decades. The voltage is higher for Li compared to Na, and thereby more efficient.

Na and K are in high concentration in sea water while Li is much scarcer. There are high concentrations at a few places like the Bolivian desert areas and in China. A problem is that Li has similar properties as Na and therefore is complicated to separate from the latter. The content in the earth's crust is 20 ppm and in the oceans 0.17 ppm.

One third of the lithium is used in manufacturing of ceramics and glass. A lot is also used in combination with aluminum and magnesium to produce light metal, which can be used in, e.g. manufacturing of aeroplanes. Lithium is also used in grease and lubricants and other similar applications.

Lithium carbonate or lithium citrate is used to treat mental illness as it has a calming effect.

6.1.9 Magnesium (Mg)

Magnesium is used as alloys with other metals like aluminum to produce light weight metals, which are used in, e.g. aeroplanes.

The content of Mg in the earth's crust is 23,000 ppm and in the oceans 1200 ppm.

In 1998, the production of Mg was 453,000 tons where the major producers were China with 120,000, the US with 117,000 , Canada 57,000, Norway 49,000, and Russia 35,000 ton. More information about Magnesium can be found in among others https://sv.wikipedia.org/wiki/Magnesiumsulfat (Mg) (2016)

6.1.10 Manganese (Mn)

This element has a very uneven distribution on earth and 80% of the reserves are situated in South Africa and the Ukraine.

Mn has a content of 950 ppm in the earth's crust and 10^{-4} ppm in the oceans.

Manganese is used primarily in steel alloys because it hardens the steel. Twenty-four percent of the Mn is actually used in construction materials like I-beams. Another 14% is used in machinery and 13% in transportation.

Another important application is as part of dry batteries, where MnO_2 is the material.

Potassium permanganate ($KMnO_4$) is used to kill bacteria and algae in water and wastewater treatment. It is also used as an oxidant in organic chemical synthesis.

6.1.11 Molybden (Mo)

Molybden is used as lubricant addition to fat and as an addition to steel to become acid proof.

The content in the earth's crust is 1.5 ppm and in the oceans 0.01 ppm.

The production is not very high and the estimated reserves quite limited: 5.35 million ton Mo in the US, 2.45 million in Chile, 0.9 million in Canada, and 0.7 million in Russia. All others have 2.4 million tons. Altogether this is 11.8 million tons.

The production in the largest mine in Colorado was 25,000 ton in 1993. Annually, the production globally is approximately 100,000 ton per year. The estimated reserves thus should last approximately 120 years at this production level.

6.1.12 Nickel (Ni)

Approximately 65% of all Nickel produced is used for production of stainless steels and another 12% for super alloys like Sanicro. The remaining 23% are used for batteries, catalysts, surface coatings, and other applications. Japan consumes ca 170,000 ton/year (2005). Kuck (2012) has made an overview over differenat minerals in the US and among others Nickel is covered.

The content of Ni in the earth's crust is 80 ppm while in the oceans $1–6 \times 10^{-4}$ ppm.

As a mineral nickel is normally bound to sulfur together with iron and arsenic. Australia and New Caledonia have the biggest estimate reserves (45% all together). The land based resources of ores with more than 1% Ni is estimated to be at least 130 million tons of Ni. About 60% is in laterites and 40% in sulfide deposits. Still, there is also probably a lot of Ni in manganese nodules at the sea bottom, but how much is not known yet. The amount of production in major countries as well as estimated reserves are seen in Table 6.2.

Table 6.2 World mine production and reserves

	Mine production		
	2010	2011e	Reserves
United States	—	—	—
Australia	170,000	180,000	24,000,000
Botswana	28,000	32,000	490,000
Brazil	59,100	83,000	8,700,000
Canada	158,000	200,000	3,300,000
China	79,000	80,000	3,000,000
Colombia	72,000	72,000	720,000
Cuba	70,000	74,000	5,500,000
Dominican Republic	14,000	1000,000	
Indonesia	232,000	230,000	3,900,000
Madagascar	15,000	25,000	1,600,000
New Caledonia	130,000	140,000	12,000,000
Philippines	173,000	230,000	1,100,000
Russia	269,000	280,000	6,000,000
South Africa	40,000	42,000	3,700,000
Other countries	99,000	100,000	4,600,000
World total (rounded)	1,590,000	1,800,000	80,000,000

https://minerals.usgs.gov/minerals/pubs/commodity/nickel/mcs-2012-nicke.pdf

6.1.13 Platinum (Pt)

Platinum and other elements in the platinum group (ruthenium (Ru), rhodium (Rh), palladium (Pd), osmium (Os), iridium (Ir)) are usually not found in concentrated form, although Pt and Pd can be found as pure metals. The content in the earth's crust for these metals is: Ru 0.001, Rh 0.0002, Pd 0.0006, Os 0.0001, Ir 0.000003, and Pt 0.001 ppm.

Platinum is mainly known for use as a catalyst in cars or for reduction of emissions from industrial plants. It is also used in the synthesis of a number of organic chemicals like pharmaceutics as well as electronic equipment like capacitors and conductive and resistive films. Of course it is also used as jewelry, where it competes with gold.

6.1.14 Potassium (K)

Both sodium and potassium are extremely important ions for all living species — crops, microorganisms as well as animals. They balance the fluids in the body and transfer electric signals in the nerves.

For K the content in the earth's crust is 21,000 ppm and 379 ppm in the oceans.

Na and K are thus very common in both sea water and in principally all biomass.

Neither Na nor K are limiting resources.

K is normally mined and extracted from potash, salts with K and SO_4 or Cl. K is used in fertilizers, normally known as N-P-K fertilizer in combination with nitrogen compounds and phosphate.

6.1.15 Rare Earth Metals

Rare earth metals is a group of 17 elements which are used in many different applications like PV-cells, computers, power generation and advanced automotive propulsion, LED-lamps, electric motors, fuel cells, generators for wind turbines, water treatment, oil refining, metal alloying, decolorizing recycled glass, communications, diagnostic health care, flat screen TVs, and hybrid cars. A lot of very important applications!

The concentration of rare earth metals is usually very low and the extraction is difficult. The elements are: scandium (Sc), yttrium (Y) and 15 lanthanides with atomic numbers 57 through 71: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu).

Scandium, 16 ppm in the earth's crust,
Yttrium, 30 ppm, in ceramics, 3–8% Y_2O_3 in ZrO_2 in lambda sond, in lasers, super conducting ceramics,
Lantan, 32 ppm, used in batteries, with Ni H_2-storage,
Cerium, 68 ppm, used to polish glass as CeO2, catalyst to crack heavy hydrocarbons, in exhaust gas catalysts,
Neodymium, 38 ppm, very strong permanent magnets,
Gadolinium, 7.7 ppm, used in TV screens, computer memories, neutron absorbers in nuclear reactors, compact refrigerators,
Terbium, 1.1 ppm, magnetostriction — can transfer waves into mechanical forces. Memory metals.
Dysprosium, 6 ppm, neutron absorber in nuclear reactors.
Holmium, 1.4 ppm, in superconductors.

6.1.16 Silver (Ag)

Silver is another precious metal which has been used in the financial sector alongside gold. It is used in electronics applications, but also a lot in households directly or in combinations with other materials; in mirrors and light reflectors. Earlier it was also very important in photography.

The mined mineral is usually silver sulfide (Ag_2S, argentite).

The content of silver in the earth's crust is 0.07 ppm and in oceans 10^{-7} ppm.

6.1.17 Sodium (Na)

Both sodium and potassium are extremely important ions for all living species — crops, microorganisms as well as animals. They balance the fluids in the body and transfer electric signals in the nerves.

The content of Na in the earth's crust is 23,000 ppm while it is 10,500 ppm in the oceans.

Na is thus very common in both sea water and in principally all biomass. Na is not a limited resource.

6.1.18 Tin (Sn)

Tin has a content in the earth's crust of 2.2 ppm and 10^{-5} in the oceans. Still, there are relatively high concentrations in minerals locally, which led to its very early use in the history of man-kind, 5000 years ago or earlier.

The world production is in the range of 200,000 ton per year as Sn. Brazil, Bolivia, and Australia are major producers, but Indonesia, Malaysia, and Thailand also produce significant amounts.

6.1.19 Uranium (U)

Uranium is one of the most important energy carriers used for electric power production.

In 2017, there were some 440 commercial nuclear power reactors operating in 31 countries, with over 364,000 MWe of total capacity. They supply 16% of the world's electricity, as base-load power, and their efficiency is increasing. This percentage has been roughly stable since 1986 (the Chernobyl accident!)

Natural uranium contains 99.3% U-238 and 0.7% U-235. After the enrichment the uranium contains approx. 3-5% of the fissile isotope U-235. The difference between the two isotopes is that the nucleus in U-238 contains three more neutrons than the nucleus in U-235; (5 kg natural uranium yield approx. 1 kg of enriched uranium). The 440 operating reactors in the world require 77,000 ton of uranium oxide concentrate from mines, (or stockpiles), each year.

In the "normal reactors", pressure water reactors (PWR) as well as boiling water reactors (BWR), only the 0.7% of uranium that is U235 is used. In the so called "fourth generation" the content of U235 is enriched to above 15–16%. Then the neutron intensity becomes high enough to also convert U238 to become U239 and then decompose to produce heat. In this case, we can principally use all U, both the 99.3% that is U238 and 0.7% that is U235. Also, long-lived isotopes such as plutonium will be decomposed, and thus we can avoid long lasting radioactivity in the waste.

There are about 3 mg of uranium per ton of sea water, about 4 g per ton of granite and up to 400 g per ton of coal. Mineral rocks contain about 3 U kg/ton.

More than two thirds of the world production comes from just ten mines. The uranium ore deposits in these mines have average grades of 0.10%. Canada and Australia are the main producers.

Ten countries have approximately 96% of all known global reserves of uranium, approximately 15–20 million tons.

The reserves are as seen in Table 6.3.

http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/uranium-resources/supply-of-uranium.aspx (U) (data from 2016)

What we can note from these different sources is that there is a very strong deviation between the estimates. The only country having lower reserves in 2016 compared to the 1990s is the US. Still, the world total is 5.7 million 2016 while estimates were 15–20 million during the 1990s which reflects what is considered economically extractable resources. When alternatives becomes more expensive higher production costs can be acceptable and as the oil price went up during the 2000s this also affected the uranium price.

Table 6.3 Known recoverable reserves of uranium

Country	Uranium (tons) (1990s)	Reserves (tons) (2016)
Australia	460,000	1,664,100
Canada	426,000	509,000
Kazakhstan	254,000	745,300
South Africa	186,000	322,400
Brazil	112,000	276,800
Namibia	110,000	267,000
Uzbekistan	109,000	130,100
USA	102,000	62,900
Niger	94,000	291,500
Russia	75,000	507,800
China	–	272,500
Mongolia	–	141,500
Ukraine	–	115,800
Botswana	–	73,500
Tanzania	–	58,100
Jordan	–	47,700
Others	–	232,400
World total	15–20,000,000	5,718,400

6.1.20 Vanadium (V)

Vanadium is used in some steels as an alloying element, but also in batteries and different catalysts.

It is often in high content in coal ash and oil. Important minerals for production of vanadium are patronite and in magnetite we often see V contents higher than 1%. The production is in the range of 17 million ton/year where South Africa produces 50% and Russia 30%. In some Caribbean oils the V content can be 6–20% in the ash.

The content in the earth's crust is 160 ppm and in the oceans 1×10^{-3} ppm.

6.1.21 Zinc (Zn)

Zinc is often used in combination with other metals. Copper together with 20–45% Zn gives brass, which is much stronger and harder than pure zinc metal. Zn is also used in combination with iron. It is then normally galvanized as a surface coating on iron as a cheap protection against rain etc. in, e.g. lamp stands. It is also used to make chemicals, paint, rubber, TV screens, fluorescent light, in dry batteries and agriculture.

The content of Zn in the earth's crust is 75 ppm and in the oceans 10^{-4} ppm.

Zn is an essential metal for all living species as it is part of a number of important enzymes.

6.2 Inorganic Materials Other than Metals

Other inorganic materials of special interest are primarily those important for living life. Livestock affects P-balance, CO_2 balance, methane emissions, and nitrogen balance. Especially, P balance is covered in detail and the EU actions to create a sustainable situation are discussed. The focus of each paper is in parenthesis at the end of each reference, such as primarily related to P or N, or covering many different elements or in some cases mostly related to how livestock interact with elements like N and P. FAO (2013) has investigated the availability of resources like Phosphorus and what elements that may be limiting for agriculture in the future.

Discussions concerning the limit of P are currently underway. Some researchers say we have already consumed 50% of the known resources, while others say we will reach this "peak-point" within some decades, while some say the resources will last at least 100–200 years.

Still, everyone realizes at least some resources are limited, like P, while others are not, like N; and we need to have good cycles for both. For P the reason is primarily the limited resource, while for N the reason is that we do not want to disturb the eco-system with too many nitrous compounds causing growth in, e.g. lakes, which affect fish and other animals by consuming oxygen when degraded.

These examples help illustrate the complexity of how to handle all kind of resources, and we try to discuss some of the aspects here.

6.2.1 Boron (B)

Boron is used in very different applications, such as in glass, ceramics, in nuclear power plants to control neutron flow or to shield from radiation, as a biocide toward mold, as water softeners, in soaps and detergents, in fire retardants, fireworks, medicine, and various minor applications. It is also used to make boron nitride, which is used as a hardener on cutting tools or for abrasives.

Boron is mainly produced from borax and 75% of it is produced in the US or Turkey.

The content in the earth's crust is 10 ppm and in the oceans 4.4 ppm.

It is also an essential trace element for green algae and higher plants used in agriculture, but has no known health effect on animals. This also makes it principally non-toxic to humans.

6.2.2 Carbon (C)

Carbon is bound to a number of different elements and is the base in both many inorganic and organic compounds.

The content in the earth's crust is 480 ppm and in the oceans 23–28 ppm, mostly as CO_3.

CO_2 also exists in the air where the content is some 400 ppm.

Photosynthesis is the process where CO_2 reacts with H_2O to form hydrocarbons, which are further refined to many different components in crops, microorganisms and animals, directly or indirectly (animals).

Graphite is a form of C that has major use in different industrial applications, such as sealing material in melt furnaces; fibers in light weight polymeric materials; strong constructions like skies, ship masts etc. Graphite also is used in lubricants and refractory material in hot furnaces with reducing atmosphere and in electric motors. Diamonds and fullerene are also kinds of graphite. The production of graphite was 650,000 ton in 1996 with the major producers China 250,000 ton, India 120,000 ton, North Korea 40,000, Brazil 36,000, and Mexico 36,000 ton.

Coal of different kinds is the major fossil fuel in countries like China, the US, and some others.

6.2.3 Chlorine (Cl)

Chlorine is a very important element for all living species as it together with Na and K balance the electrolytes in the body.

The content in the earth's crust is 130 ppm but 18,000 ppm in the oceans.

Chlorine is also used in many technical applications, for instance as Cl_2 to kill off bacteria in water, as a bleach substance in the pulp and paper industry, as the acid HCl used in many chemical processes etc.

Chloro-organic compounds are normally very stable for good and bad. PCB, DDT, chlorinated solvent, dioxine, and similar substances have proven to be very bad for human health and are principally forbidden to use in many countries.

6.2.4 Fluorine (F)

Fluorine is the "little brother" to Cl. The content in earth's crust is 950 ppm while only 1.3 ppm in the oceans.

It is used in metal processing to make slag with lower viscosity, the acid HF is used to dilute SiO_2, F is an important part of the plastics PTFE and PVDF, and coolants like freons include F in different proportions.

6.2.5 Halogens

The halogens are F, Cl, Br, and I. The most important are the two first. Iodine (I) is used in organic synthesis but is also needed for human health. Bromine (Br) is used in fire retardant materials, but due to health issues use has decreased.

6.2.6 Hydrogen (H)

Hydrogen is a very special element because it is so light. It is the major molar part of water as well as in most organic compounds. It is not a limiting resource, and thus we do not discuss it in detail in this book.

The content of hydrogen in the earth's crust is 1500 ppm and in water 11.1 weight %.

6.2.7 Nitrogen (N)

Nitrogen is one of the base elements in all living species including animals, crops, and all microorganisms. N is in protein, genetic material like DNA, but also in many other organic molecules. Since, nitrogen is 79% of air there is no limitation in available resources as such, but the question is on how to convert this N_2 into organic or inorganic compounds that can be used by living species.

The content of nitrogen in the earth's crust is 25 ppm and in the oceans 10^{-4} to 0.5 ppm.

In nature the most important conversion is made by microorganisms in, e.g. rhizome around the roots of leguminous crops in soil or in cyanobacteria in water. Then N_2 is transferred into inorganic components like NO_3 and further converted to NH_3, but also into complex molecules like amino acids and proteins.

From an environmental perspective N-compounds can be problematic, e.g. N_2O is a very potent greenhouse gas, some 300 times worse than CO_2. If NH_4 or NO_3 leak out to the sea and lakes, and there is also enough P, algae and crops can form mats of biomass where clear water is preferred. Then when this dies and degrades oxygen is consumed and fish and other species die.

The nitrogen cycle and how animals utilize nitrogen compounds is described in detail in Steinfeld et al. (2010). A summary of the flows of N as Tg N/year is seen in Fig. 6.5.

We can see from this balance that the N from anthropogenic sources today is in the same order of magnitude as from natural biological conversion. Globally, cropland gets 170 Tg N/year from which 49 Tg N/year becomes food for humans (1/3) and animals (2/3). The rest is lost to the surroundings or recycled back into the system. Of the 33 Tg N/year going into animals only 5 Tg N/year becomes human

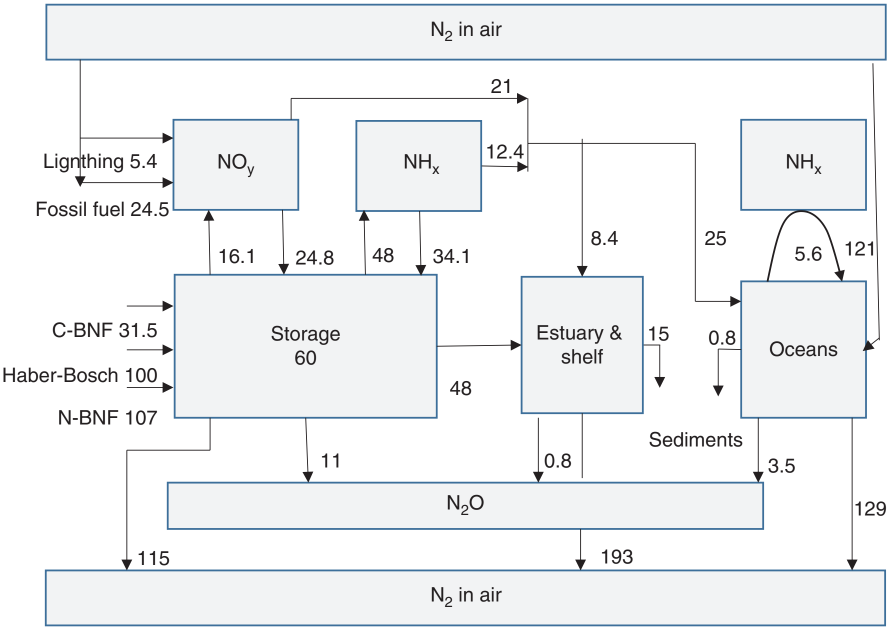

Fig. 6.5 Nitrogen balance from Steinfeld et al. (2010). C-BNF is biological nitrogen fixation in agriculture while N-BNF is in nature. Haber-Bosch is the chemical process for production of NH_3 (ammonia) from $N_2 + H_2$ (hydrogen)

food. Bouwman et al. (2005) developed balances for intensive agriculture, while Smil (2002) investigated nitrogen and protein in food diets.

6.2.8 Oxygen (O)

Oxygen is in water, most important minerals, such as carbonates, sulfates and oxides, and is 21% of the air (O_2). Thus, we can conclude that oxygen is not a limiting resource.

The content of O in the earth's crust is 474,000 ppm or 47.4%, and is thereby the most frequent element on earth. It is also by weight the dominating part of all water.

We must also keep in mind that oxygen is essential for all animals to survive. During photosynthesis crops take up CO_2 and H_2O and release O_2 during respiration.

Oxygen is included in all important reactions in our bodies.

A variant of oxygen is ozone, which is used as a strong oxidant in chemical reactions like degradation of organics in water treatment or as a bleach agent in pulp manufacturing. Ozone also is the molecule that protects humans from strong radiation from space due to the characteristic to absorb this in the atmosphere.

6.2.9 Phosphorous (P)

Phosphorus as phosphate is one of the major energy carriers in mitochondria, all living species' "power plants". It is also very important as part of the DNA spiral. Due to this, both animals and crops need a certain amount of phosphorus for growth and survival. Animals get it from food while crops need to take it up from soil (most crops) or water (e.g. algae).

By adding phosphate to crops the yield per ha can be increased significantly. A lot of the nutrients come from manure from breeding animals like pigs, chicken and cows, but in many countries today mineral fertilizers are even more important in crop farming.

Phosphate is also used as a softener in tensides for washing, although the amount is decreasing in many countries. Residual phosphorus in effluents needs to be removed to avoid growth of, e.g. algae, water hyacinth, and other crops. This is done in waste water treatment plants. The most efficient way is to add metal salts like $AlCl_3$, $FeCl_3$ or sulfates. Then strong precipitates of $AlPO_4$ and $FePO_4$ are formed. Unfortunately, these are very stable and do not dissolve much when recycled to farm land. Another removal method is to incorporate P into microorganisms and algae already in biological waste water treatment. After biogas production from the biomass, the residues can be distributed to farm land and utilized in an efficient way as nutrients by many crops.

The content of P in the earth's crust is 1000 ppm and in the oceans 0.001–0.085 ppm depending on location.

Christian Pallière gives figures (Fertilizers Europe in 24–27 May 2011, Green Week in Brussels) on P-resources and reserves. The resources are estimated at 300 billion tons of P-rock while the reserves are approximately 60 billion tons. Approximately 15 billion tons are in existing mines. The known reserves are estimated to last 300 years, while resources approximately 1500 years at today's level of usage. Of the phosphate mined 82% is used as fertilizer, while 7% is used in animal feed. This shows the importance of phosphate for production of both crops and animals.

IFA Production and International Trade reports that 31% of P is used in China, 19% in India, 9% in Brazil, 9% in the US, 5% in the EU, and the remaining 27% in the rest of the world. The phosphorus is normally presented as P_2O_5 and 10 million tons were used in developed countries in 2013, which is much less than 1980 when 17 million tons were used. For developing countries, the use went from 8 million tons in 1980 to 33 million tons in 2013. At the same time, the production of crops has doubled as tons per ha in both developing and developed countries. It shows that the developed countries have learned to use fertilizers more efficiently. The trend will be the same for developing countries.

A problem is that minerals containing P also often contain other less wanted elements like cadmium (Cd), which presents problems as Cd is enriched in soil and can be taken up by cereals. This can then increase risks, e.g., kidney cancer when people eat the crops. Thus, to avoid this a number of countries have put strict demands on P fertilizer specifying maximum Cd levels, which differ a bit between countries.

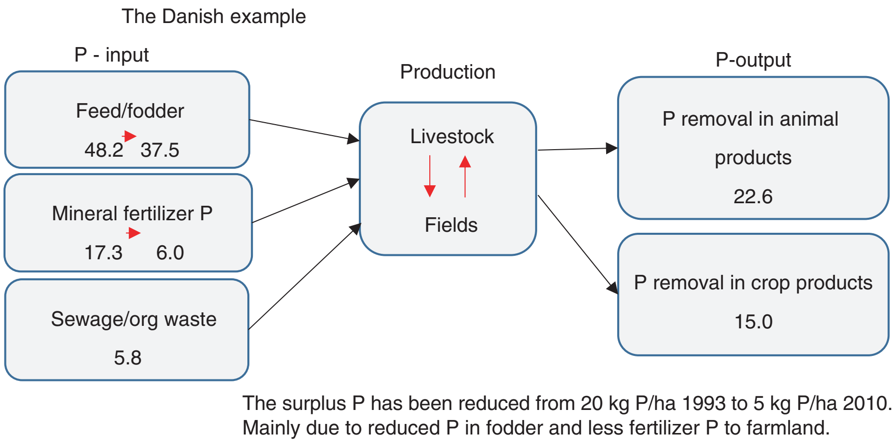

Fig. 6.6 How Denmark decreased surplus of P from 20 to 5 kg P /ha from 1993 to 2010 by decreased P in feed (fodder) and mineral fertilizer to the farmland (From Lars Stoumann Jensen (2011))

If we could recycle all P removed in waste water treatment plants to farmlands the demand of new P would decrease significantly. The problem still is the difficulty to utilize the P in metal precipitates as well as the risk of polluting the soil with unwanted elements and organic components. A priority will be to avoid heavy metals and similar being emitted into sewers and reaching the WWTPs. Separation of run-off water from sewers is a first step that has been implemented in many cities, but many still mix the flows.

An example from Denmark by Lars Stoumann Jensen (2011) demonstrates better P recycling. Figure 6.6 shows how the P surplus was reduced from 20 kg P/ha to 5 kg P/ha from 1993 to 2010. Especially, the mineral fertilizer amount was reduced from 17,300 ton P in 1993 to 6000 ton P/year in 2010 in Denmark.

From an EU perspective 3 kg P per European citizen per year comes from foreign mines.

Thus, from the EU perspective it is important to reduce the loss of P per hectare and per unit produce (liter milk, kg meat, kg grain...). Of course, this is also the case in most other countries and regions lacking big internal resources of P—that is most countries in the world!

China has approximately 6.6 billion tons, Marocco and West Sahara 51 billion, the US 1.4 billion and South Africa 1.5 billion according to Lars Stoumann Jensen, in "The Globe Needs Sustainable Solutions for Phosphorus Recycling", at Green Week in Brussels, 21–24 May 2011. A problem is that the estimates are quite weak, e.g., the figure for Marocco and Spanish Sahara only 10 years ago was estimated to be just 5.7 billion tons. The saturation with respect to P in soils varies a lot between different countries. In the EU, Finland has more than 50% of the soils with poor or low content of P while Norway has only 2% and Denmark 5%!

From a crop production perspective competition between different species may favor one crop species in relation to another. Turner (2008) studied this and saw that there are probably synergies between different species helping each other. As P can be in different organically bound forms different crops, mycorrhizas, and microorganisms can help each other decompose and take up different compounds. Normally, organically bound P is some 35–65% of all P in the soil, but sometimes even >90%.

In 2011, the EU commission sent a report to the parliament about how to create a resource efficient Europe: Roadmap to a Resource Efficient Europe (2011). In 2012, the JRC published the report EUR 25327 EN “NPK: Will there be enough plant nutrients to feed a world of 9 billion in 2050?” (2012). This was followed by a report on the basis of an explicit commitment in the Roadmap to a Resource Efficient Europe. EU Commission (2013) published this as a Consultative Communication on the Sustainable Use of Phosphorus. Here, important stakeholders were asked about their view on P-resources in the future. The results were published [2014] as “responses to the Consultative Communication on the Sustainable Use of Phosphorus”. 125 replies on 11 questions were received. 2/3 say they are concerned about P in the EU in the future. The majority believe it is a problem that the figures about available P resources deviate so much, but otherwise most agree on the overall picture about use and resource availability in the future. Half still believe the information about available resources is not transparent, but should be. Many are concerned about impurities like Cd, but also that recycling of P should be done and thus this problem solved. Recycling of municipal sludge should be a focus. How to do this should be investigated further in R&D projects. Manure management should also be addressed. In some areas there is a surplus of manure, while deficiency in others. To avoid pollution of P, waste should be sorted and collected as clean fractions to avoid mixing metals into, e.g. house hold waste. These aspects shall also be mostly valid on a global perspective, and should be good guidelines for all governments to work toward. Gautam et al (2011) has studied how Phosphorus is taken up in corn under different conditions. This can be more efficient in some hybrids.

6.2.10 Silica (Si)

Silica is normally bound to oxygen in nature, SiO_2 or SiO_3.

The content in the earth’s crust is 277,000 ppm or 27.7% while the content in the oceans is in the range 0.03–4 ppm, depending on location.

Silica is the base of most sand and clays, and is utilized in building manufacturing, ceramics, glass, and as glass fiber fillers in plastic. After reduction of SiO_2 to Si, crystals grown from the solution can be made into elemental mono crystalline silica, which after doping becomes PV cells. This has become very important since the price has fallen dramatically over the last few years as the manufacturing techniques have become very efficient, especially in China.

The sources are principally everywhere, so this is by no means a limited resource!

6.2.11 *Sulfur (S)*

Sulfur is also very common because there are huge amounts in sea water as SO_4 and in sulfite minerals. As it is essential in several amino acids, it is also part of many oil and coal qualities, which emanate from living species.

Thirty years ago sulfur emissions were problematic in many countries and emitted SO_2 destroyed buildings ($CaCO_3$), bridges, decreased production in forests due to acidification, killed species in lakes etc. Since the 1980s, many power plants have reduced the emissions by using coal with a lower content of sulfur and addition of $CaO/CaCO_3$ in scrubbers to remove SO_2. However, the emissions are still very bad in some developing countries.

The content of sulfur in the earth's crust is 260 ppm and in the oceans 870 ppm, in the form of SO_4.

A certain amount of SO_4 is needed for crop production. Normally, there is no deficiency of this. Otherwise, the most common use of S is for production of sulfuric acid, which is used in mining of different metals.

6.3 Fossil Organics Like Peat, Lignite, Oil, and Natural Gas

It may be a bit illogical to have peat, oil, NG and lignite under inorganic materials. They are produced from old organic material (fossil fuels) or more recent (peat), but are all considered as fossil materials.

There are enormous amounts of natural gas (NG) in many countries and under the sea bottom. Huge amounts may also be bound in soil in arctic regions and as ice, methane hexa hydrate, at the sea bottom. No one knows the amount, but probably ten times as much as the known resources of oil. A major concern here is that global warming may cause a release of methane from hexa-hydrates and soil if arctic areas are heated. This might give an uncontrollable temperature increase in the atmosphere due to green house gas mechanisms, as methane is 25 times stronger than CO_2 as a green house gas.

Concerning oil, much indicates that we have already extracted and used more than half of existing extractable resources. Normally, approximately 35% of the oil in a well is taken out by just the pressure. Up to another 1/3 can be extracted using enhanced oil recovery by washing with tensides or CO_2. This will cause problems with deficiency within some 50 years if we proceed as we have done over the last 50 years. As the resource becomes scarce the price should go up and the consumption down, but even if this is true long term, there may be many bumps in the road!

Concerning lignite and other coal qualities the resources are huge. The problem with the use is primarily environmental impact with release of large amounts of small soot particles, causing diseases like asthma, allergia, cancer etc. Still, it is used in countries with large internal resources, like China, the US, South Africa, and others. Therefore, it is strongly demanded to get alternative energy sources implemented to replace the power produced from fossil fuels, especially coal.

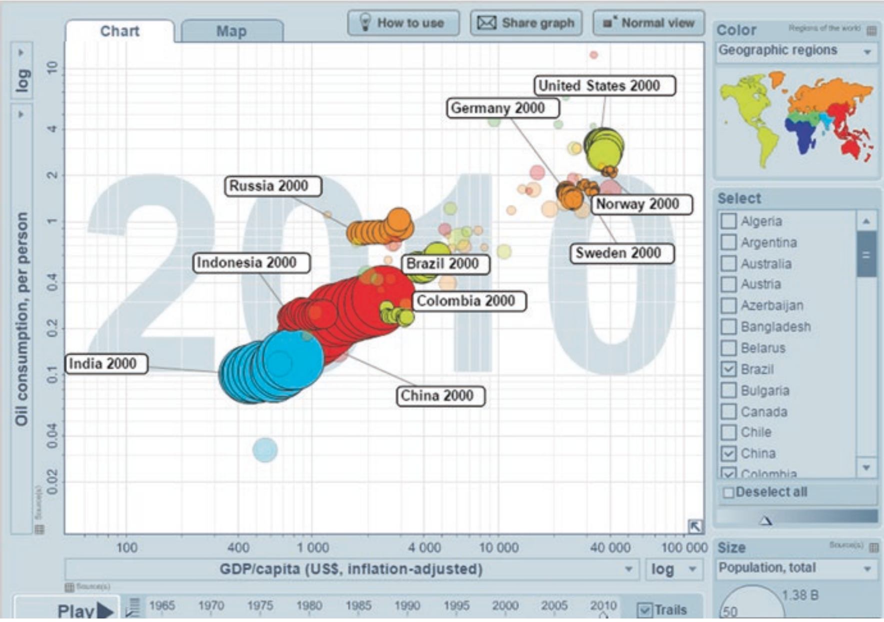

Fig. 6.7 Oil consumption per person as a function of GDP per capita from 2000 to 2010 for some selected countries

As we have already shown, principally all fossil fuels can be replaced by biomass if it is used efficiently. However, the incentives to go this path depend on what regulations are implemented. If it is more costly to use biomass, and nothing is added such as tax to compensate for negative effects like global warming and air pollution, then it is very difficult to get a good development. At the same time, it is also important to use good technology for conversion of biomass, so that we do not cause air pollution. Here, we rely on regulatory demands from the governments (Fig. 6.7).

The oil consumption per person increased in India, China, Russia and Brazil, while it was more or less constant in Indonesia, Colombia, Sweden, and Norway and even decreased in the US during the period 2000–2008 (Fig. 6.8).

China increased natural gas consumption per capita significantly during the period 2000–2008 while Germany decreased their consumption. The others have roughly the same consumption per capita during the period, but all increased the GDP per capita except the US and Norway.

We can see in Fig. 6.9 that coal has increased strongly in China, India, and Indonesia while the US, Germany, Russia, Brazil, and Colombia have increased GDP but not coal consumption during the period 2000–2008.

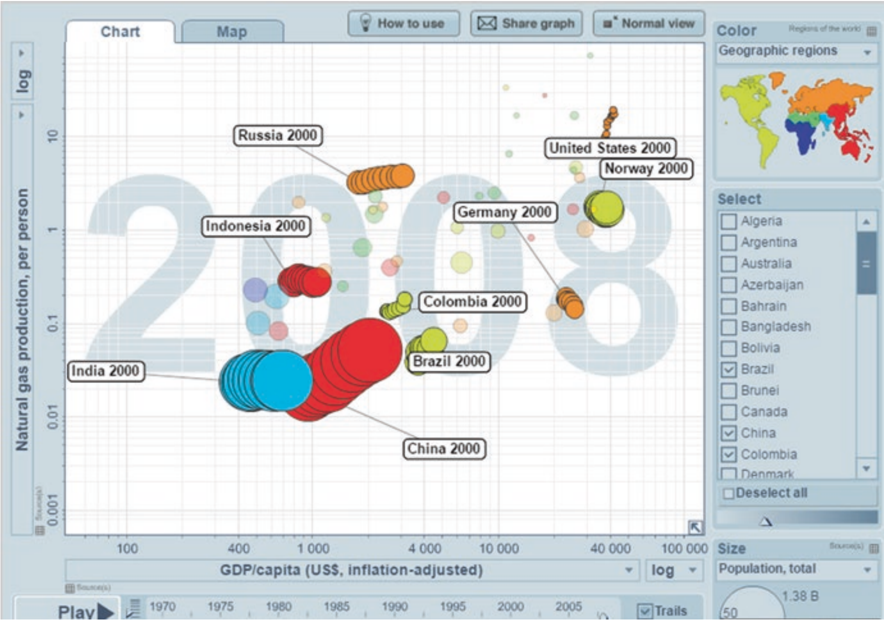

Fig. 6.8 Natural gas production per person versus GDP per capita from 2000 to 2008 for some selected countries

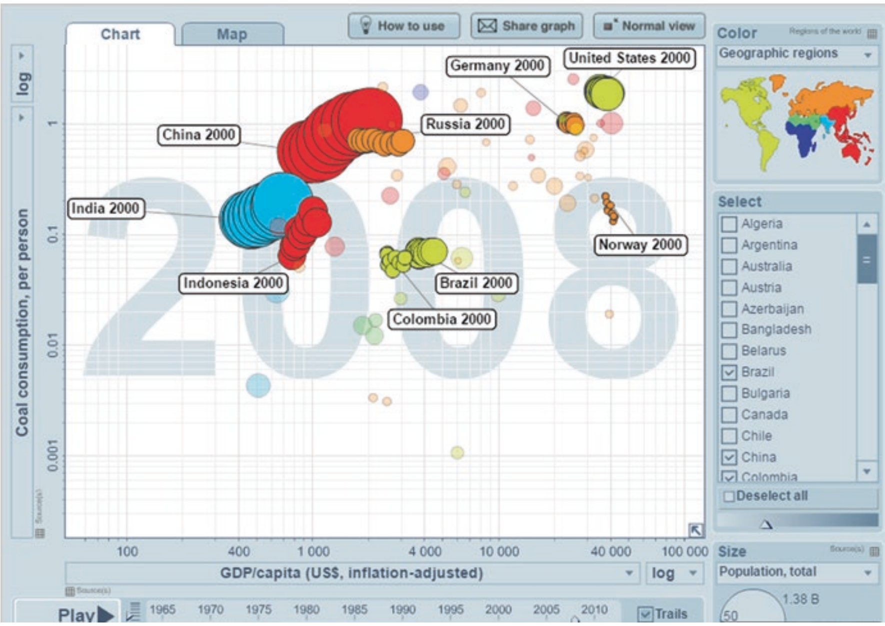

Fig. 6.9 Coal consumption per person versus GDP per capita from 2000 to 2008 for some selected countries

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Chapter 7
Reuse and Circulation of Organic Resources and Mixed Residues

Elias Hakalehto and Ari Jääskeläinen

7.1 Introduction

In the history of mankind, the relatively short period of industrialization has determined the cross-effect of our existence toward the global environment and its resources. As a determinative factor, the strive for better standard of living as well as for technological progress have given the face to our modern societies. A quotation from “The Sixth Extinction” by Elizabeth Kolbert (2015): “… Having discovered subterranean reserves of energy, humans begin to change the composition of the atmosphere. This, in turn, alters the climate and chemistry of the oceans…”.

Energy efficiency is designated as the “fifth fuel” (Hallett 2013). Different modern technologies should favor its implementation. In a way, increasingly efficient use of the chemical energies of the various side streams could serve that purpose. In the long term, it could increase the cost-effectiveness and sustainability of societies at the same time.

At present, in order to restructure our way of living during the post-industrial era, it is crucial to put weight on recirculation. This could open up novel technological solutions which will help in balancing the human impact on the global ecosystem.

This novel trend was initiated by the environmental movement some 50 years ago. The reorientation of societies as a whole always starts on the individual level, as the small beginnings and encouraging experiences could set an example for our future collective behavior.

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Springer International Publishing AG 2017
E. Dahlquist, S. Hellstrand (eds.), *Natural Resources Available Today and in the Future*, DOI 10.1007/978-3-319-54263-8_7

7.1.1 First Case of Sorting Out the Household Biowaste in Finland 1984

Starting in 1984, the Student Union of Helsinki University funded a suburban scale experiment on household sorting in Finland. The trial was organized for the first time in Finland in the Latokartano complex of student dormitories in Eastern Helsinki, close to Viikki campus for agricultural studies. This student dwelling area has always had a system of local democracy with representatives from each house (houses called "koukku" = "a hook") which are named after the figures of the Kalevala national epoch to Sampsa, Pellervo, Osmotar, Kaleva, Kaski and Pelto hooks. The meetings are chaired by an "olterman". This administrative structure was suggested in 1953 by the academician Kustaa Vilkuna, and the area was completed in 1974 (Savolainen 2003).

On the basis of the unique social pattern, the waste sorting experiment became highly successful, and it produced lots of important information for later activities all over the country. Nowadays, 95% of the Finns advocate the sorting of household residual fractions. The Viikki area has grown into a large campus area and is one of the four main campuses of the Helsinki University, as well as a home for over 11,000 citizens (2010). There is also an area where the ecological architecture has been implemented into family houses (Fig. 7.1). Ecological construction has a significant role in Viikki plans and implementation. There is a national housing construction test area. The buildings widely utilize solar energy and energy efficiency solutions. For Eco-Viikki, special criteria were compiled for ecological construction, which directed construction into a more environmental friendly direction. The household waste sorting has been included in the local landscape for many decades in Viikki (Fig. 7.2a, b). Criteria measured ecology of construction projects from five points of view:

Fig. 7.1 Ecological construction in Viikki area (Photograph by Ilari Heitto)

Fig. 7.2 (**a**) Waste collection shelter, into which the separated wastes are collected; (**b**) One of the student housing units in the Latokartano dormitory (Photographs by Ilari Heitto)

Fig. 7.3 View on part of the new campus in Viikki area locating the departments for biological studies of the University of Helsinki (Photograph by Ilari Heitto)

- Pollution
- Use of natural resources
- Healthiness of buildings
- Natural biodiversity
- Food production.

Numerous ecological energy and environmental solutions were implemented in the area estates. Most of Viikki's ecological test construction utilized passive and active solar energy opportunities (City of Helsinki 2016). This suburban location is the home of one of the four major campuses of the University of Helsinki in the midst of a lively neighborhood (Fig. 7.3).

7.1.2 *Current Household Biowaste Treating in Helsinki and in Stockholm*

Helsinki Region Environmental Services Authority HSY is a municipal body, which produces waste management and water services, as well as provides information on the Helsinki Metropolitan Area and environment (Helsinki Region Environmental Services Authority 2016).

In order to rationalize the biowaste processing, it could be possible to get rid of the demanding logistics with the sorted biowaste collection containers from various suburbs and collection centers. Their reception at the HSY waste treatment area near Helsinki, Finland, corresponds to some 200–250 tons daily. Consequently, the automated hall for emptying the containers (Fig. 7.4a), and for pretreatment (Fig. 7.4b), is relatively sizable. Currently, the main product from the biowastes is (1) biogas from which electricity and heat are produced and (2) compost (Fig. 7.4c).

In Stockholm, Sweden, the sorted biowaste has been partially collected for biogas production using household water for its collection. Food waste is washed away with tap water, and the organic wastes are recollected at the site of utilization (Karlberg and Norin 1999).

Estate-specific biowaste collection systems have also been piloted in Stockholm. The installations mean that food waste is put without packaging in the inlet, ground or dispersed, diluted with some water, and stored in a closed tank as slurry. This can be implemented in many technical ways, such as

- Integrated inlet with grinder together with tank,
- Grinder at inlet and suction of slurry to tank and
- Suction of waste from several inlets and one grinder placed with collection tank.

The tanks can sometimes be connected with overflow of excess water to a fat trap, which is connected to the sewage pipes. The city's water company is involved in the development (Stockholm Vatten 2011).

Inlets are placed in the kitchen, to food preparation and dishwasher areas, connected with suction pipes to the central grinder, tank and vacuum pump. The tank room can be placed under street level. Smaller systems can have an integrated work top with inlet to grinder and tank in the same room. Access to water and sewage is necessary both at the point of inlet and in the tank room. Ventilation/outlet to air is necessary for the vacuum pump, as well as for the general ventilation of the tank room.

Based on the experiences from the experiments there are the following limitations:

- Large tough fish skins
- Hard bones and items

Fig. 7.4 (**a**) The sorted biowaste reception unit automatically handles baskets or containers from all over the cities in the Metropolitan Helsinki area with the daily waste input of around 200–250 tons. (**b**) Different organic wastes are homogenized and pretreated for a biogas unit. (**c**) Biogas is one of the main products of the HSY waste treatment plant in Ämmässuo, Espoo, close to the border with Helsinki. (Photographs by Elias Hakalehto)

- Long fibres
- Cutlery

that can cause stoppages. The dry matter (DM) content in the slurry should be around 12–15% and with a "pumpable" viscosity. If the slurry is too thick, it is difficult to empty the tank, and water has to be added to dilute the slurry. Two to three week intervals would be appropriate for emptying the tank.

The heavy vehicle movements can be reduced to at least half if the tank volume is dimensioned to be emptied twice a month. Waste generators with large amounts of food waste normally have collection at least one time per week, often even three to five times per week. A better separation also improves the properties of the remaining waste: it is lighter, drier and can sometimes be compacted. In total, the numbers of heavy lorry movements are reduced significantly at the waste generator. The slurry may contain more water to be transported but on the other hand the practical pay load of the sludge vehicle (10 tonnes) is bigger than for the conventional waste truck (7 tonnes) (Millers-Dalsjö and Lundborg 2012).

Any processing of organic wastes with water would warrant proper hygienic measures. This is especially important if there is a risk for the microbial contamination of the drinking water. It is widely recognized that the microbiological monitoring of clean waters should be improved. Even in developed countries hazardous contaminations of the water pipelines have taken place causing gastroenteric infections for high amounts of people. For enhanced microbiological monitoring of the water hygiene, e.g. a Coliline PMEU version of the Portable Microbe Enrichment Unit has been developed (Hakalehto et al. 2011, 2013). See Fig. 7.5. It could also be

Fig. 7.5 PMEU Coliline™ unit is equipped with Automated Sample Collection System for online monitoring of clean water in water departments and in the distribution system. The unit can be connected directly to the water tubing (See also McCoy 2015). (Photograph by Jouni Pesola)

connected with centralized water quality monitoring processes and with automated sample collection systems of the water departments. Such installation is currently under construction at the water department of the city of Mikkeli, Finland, and it has been tested in several water companies (Hakalehto et al. 2011, 2015).

Also, the quality of the environmental waters could be affected by processing of the organic wastes. The microbiology of the lake water samples, for example, were studied by the PMEU method (Hakalehto and Heitto 2012; Hakalehto et al. 2014). The findings were applied to trace the sources of the wastewaters leading to disturbances of the microbiological balance (Heitto et al. 2006, 2009).

7.2 Role of Microbes in the Circulation

Most organic materials cycle in Nature. This takes place by solar energy, which is bound to the chemical bonds in biological matter.

Equally important with the collection of the exposed light energy is the return of the so formed organics back to the circulation by the actions of various soil microbes. They also facilitate the cycles of carbon in Nature (Hakalehto 2015a). This process relates to the degradation of biomass, which is a big issue for communities, industries and agriculture (Hakalehto et al. 2013; Thorin et al. 2013; Hakalehto 2015b). Such a microbiological process is at the heart of a biorefinery (Hakalehto 2015b). This concept was tested in the ABOWE project during 2012–14 in the Baltic Sea region countries.

7.2.1 Historical Background and Outcome of the REMOWE and ABOWE Projects

EU Baltic Sea Region Programme 2007–2013 project REMOWE (Regional Mobilizing of Sustainable Waste-to-Energy Production, 12/2009–12/2012) was established with a new partnership, involving a diverse group of organizations, all with interest to develop forward waste utilization. REMOWE aimed to contribute to a reduction of carbon dioxide emissions by catalyzing utilization of waste from cities, farming and industry for energy purposes (electricity, heat, fuels) in an efficient way in the Baltic Sea region. Project partners from Sweden, Finland, Poland, Lithuania, Estonia and Germany represented both far developed regions in the field as well as regions in which the level of energy utilization of waste was low at that time. For example, Germany's experiences of producing biogas were shared and transferred through the project to other regions (Mälardalen University 2016).

The REMOWE project described the current status of waste management, waste policies and waste-to-energy technologies in five countries. Further, a study of State-of-Art in Waste-to-Energy production was compiled (Thorin et al. 2011). A novel biorefinery concept, innovated by Adj. Prof. Elias Hakalehto as well as dry digestion is identified in this report. In REMOWE, Ostfalia University of Applied Sciences under the leadership of Prof. Thorsten Ahrens performed biogas potential tests in laboratory on different wastes from the partner regions following the principle of wet digestion. Based on the results another principle (dry digestion) was reported as a potential future system for biogas production from household waste in partner regions. Moreover, within REMOWE, special regional innovation processes were conducted in five Baltic Sea Region countries to find new ideas for mobilizing waste-to-energy production. The novel biorefinery concept was evaluated to possess the highest innovativeness and sustainability among the ideas presented in Finland and Estonia; it also ranked high in Poland. The dry digestion technology was also ranked high in REMOWE evaluations (Lõõnik et al. 2012). A regional model was piloted in Finland by the University of Eastern Finland, efficiently calculating regional waste-to-energy potentials and related climatic and economic impacts based on regional data (Huopana et al. 2012).

The ABOWE project (Implementing Advanced Concepts for Biological Utilization of Waste, 12/2012–12/2014) was an extension stage of the REMOWE project within the Baltic Sea Region Programme 2007–2013. In ABOWE, these two technologies were piloted and tested in semi-industrial mobile pilot plants. These pilots are Pilot A Novel Biorefinery based on the concept from Adj. Prof. Elias Hakalehto, Finland (Fig. 7.6) and Pilot B (based on a German Dry Fermentation process). Pilot A was tested in Finland, Poland and Sweden and Pilot B was tested in Lithuania, Estonia and Sweden. Based on the testing periods, business models were drafted and introductory seminars were organized in each region. Also the feedstock potentials and climatic impacts of the new processes from the regions'

Fig. 7.6 Pilot A Novel Biorefinery arriving at its Polish testing site at ZGO Gać Ltd's waste management centre in Lower Silesia. Industrial levels of microbial metabolites, such as organic acids, alcohols and hydrogen, were obtained from the carboxylate wastes of food industries, as well as sorted biowaste. For a survey of the results, see den Boer et al. (2016a, b; Hakalehto et al. 2017a) or www.abowe.eu (Photograph by Mika Ruotsalainen)

perspective were evaluated with the regional model developed in REMOWE. The desired outcome from ABOWE was implementer- or investor-driven continuation projects targeting full scale plant investments of the two technologies (Savonia University of Applied Sciences 2016).

During the ABOWE project testing periods with the mobile novel biorefinery pilot plant, it was possible to give a proof of concept in Finland, Poland and Sweden with various biomass waste materials that Pilot A biorefinery could operate as an upstream biorefinery for all kinds of organic wastes. The products are biofuels, bioenergy, organic platform chemicals and organic fertilizers. These are to be produced in an economically feasible way, with the help of microorganisms. Pilot B (dry digestion), on the other hand, provided proof of concept in Lithuania, Estonia and Sweden (Freidank et al. 2014). The ABOWE piloting revealed the potential of total planning in biotechnical waste utilization and bioprocess design. For example, the Pilot A type of biorefinery's residues could be effectively utilized as raw materials in the Pilot B type of dry digestion biogas production unit. This was confirmed by the results from the Swedish test runs (Dahlquist 2016; Hakalehto et al. 2016a; Schwede et al. 2017). Depending on the type of the particular fractions, any solid fractions could then be used as organic fertilizer, composted or combusted. Gaseous emissions could be at least partially redirected into the biorefinery, which enable the recollection of their thermal and chemical energies. For example the carbon oxides and some volatile nitrogen compounds could then be bound into the biomass in the Pilot A type of biorefinery (Hakalehto et al. 2016b).

The ABOWE project was chosen as the winner among the projects of all Finnish universities of applied sciences in the series Soveltava tutkimustieto ja innovaatiot (Applied Research Knowledge and Innovations) in the national KÄRJET 2013 ("SPEARHEADS") competition (Savonia University of Applied Sciences 2016).

7.2.2 What Is Biorefinery Technology? – Theoretical and Practical Considerations

In a broader sense, every action that upgrades the technological or economic value of a biomass, could be considered as "biorefining". Moreover, any improvement in the environmental quality of a biomass waste or side stream could also be tagged as a biorefinery function. In today's world, even any activity that facilitates the circulation of carbon in the industries, biosphere or environment, belongs to that discipline.

On the basis of the considerations above, "biorefining" is actually an "umbrella" for all processes or activities, where carbon is recycled effectively in a useful way. The opposite of conceptual definition is a situation, in which carbon is naturally liberated or deliberately allowed to go, or disappear, or left unexploited.

Consequently, any combustion should be designated as a non-biorefinery. However, there are processes where the incineration gases are directed into a bioprocess for the microbes to assimilate it (Hakalehto and Ojala 2016). This very principle of carbon assimilation was taken up in 1939 by famous Dutch microbiologist Kluyver in his lecture in Helsinki (Kluyver and van Niel 1956). A quotation of the book and the chapter by Prof. Kluyver of "Evidence for Life's Unity":

> The carbon dioxide consumption established in 1936 by Wood and Werkman in the fermentation of glycerol by a propionic acid bacterium offered a most striking example. Indications that this phenomen would be of a much more general occurence were present, but in a lecture read in 1939 in Helsinki I thought it safe to express myself on this subject in the following cautious terms: "For the moment a lecturer will still meet with energetic protest if he pronounces that the cattle in the pasture, or even his audience, assimilates carbon dioxide. And yet the temptation to make such a statement is already there." In the next 2 years the introduction of either radioactive or stable carbon isotopes in metabolic studies irrefutably established that, indeed, in the cells of very diverse heterotrophic microbes, as well as in those of animals, the carbon dioxide molecule also lacked the high degree of biochemical invulnerability which had so long been attributed to it.

This situation above implies to the fact that microbes are an integral part of any biorefining function, and any circulation process whether it is a naturally occurring, or an industrial one. This relates to the ways, by which the microbes handle organic substances. In the agricultural fields these activities take place in soil. Therefore, the soil could be compared to a natural biorefinery. In both cases, the gaseous compounds play an important role in the circulation events (Hakalehto et al. 2017b).

7.2.3 Special Features of the Circulation Phenomena

In fact, soil is a poor environment, where the optimal nutrition, or functional nutrition for any microorganism is scarce. On the other hand, microbes manage to handle this "scattered ecosystem condition" almost as well as they can manage in the "enhanced ecosystem" of the intestinal tract of man or animals (Hakalehto 2012). This relates to their wide metabolic capabilities as a community.

Circulation would be most eloquent if the organic substances were used for plant or other photosynthetic organisms. Then the wastes would return to the food chains from the bottom level by the soil microbiota. However, a major portion of biowaste is refined directly to biofuels. Then the problem with the replacement of the food or feed use by the conversion into energy becomes an issue. The International Energy Agency states the following about the net energy balance of corn-to-ethanol process (IEA 2004).

> There has been considerable discussion recently regarding the net energy gain from producing ethanol from grains. Some research has suggested that it may take more fossil energy to produce a litre of ethanol (i.e. to grow, harvest and transport the grain and convert it to ethanol) than the energy contained in the litre. This would suggest that conversion losses wipe out the benefit of the renewable energy (i.e. sunlight) used to grow the crops. The non-solar energy used in the different stages of the process is primarily natural gas and coal. Only about one-sixth of the fossil energy used to produce grain ethanol in the US is estimated to be petroleum.

On the basis of the considerations above, the most effective overall solution ecologically would be the return of organic residues to the fields, forests and greenhouses after their economically utilizable compounds have been recovered.

This collection and reuse should be accomplished according to the ecological principles. In soil, the focus has to be on the sustainability. There the microbiome essentially determines the elementary cycles in a healthy situation.

7.2.4 Biogas

Biogas contains 40–70% methane, 30–60% carbon dioxide and depending on the variety of the material used for the digestion (e.g. waste) also H_2S and NH_3 as well as traces of chlorine and fluorine can occur. It is produced using microorganisms that transform the raw material into methane and carbon dioxide in an anaerobic digestion process. In Nature methane is formed, e.g. in landfills, wetlands, animal intestines and bottom layers of surface waters. As raw material for biogas, e.g. biowastes, animal manure, waste water treatment sludges and plants can be used. Biogas offers a renewable traffic fuel option whose emissions are only 10% of those of gasoline and diesel (Kivimäki 2007; Ahrens 2007). Conventional utilization of biogas is heat and electricity production which improves energy self-sufficiency of farms, waste water treatment units, factories, etc.

In 2008 Gasrec Ltd., Veolia Environmental Services and Iveco began a commercial trial of a CBM (compressed biomethane) -powered street cleansing vehicle in Camden, UK. At the same time, Gasrec and The London Borough of Camden announced Gasrec's installation of London's first biogas fueling station at the Borough Council's York Way Depot to support the trial. The facility was capable of providing the trial Iveco Daily vehicle with fuel for its 60 mile per day route for an initial period of 6 months. Gasrec was supported in the project by their fuel logistics partner the Hardstaff Group and by technology consultant Igas.

This step allowed for more convenient refueling for the trial vehicle and highlighted the suitability of CBM for back-to-base operations. It also widened the scope of the trial to allow evaluation of a complete, scalable solution, and provided the opportunity for the Borough Council to fuel vehicles in its own fleet from the York Way Depot.

This step helped underscore the potential for further commercial fleets, both within additional London Boroughs and other key UK locations. The solution aimed to be beneficial both in terms of environment and costs. It is important for the UK to minimize the imports of vehicle fuel from abroad and this step aimed to pave the way for using fuel sources that are home grown and also carbon neutral, to the benefit of society as a whole. Camden Council aimed to fuel part of Camden Council's own fleet, helping to protect the environment and save money (Energy Tech 2008).

In 2015 the UK Government approved the Biogas Strategy and Action Plan. The objective is that biogas production will reach 20 TWh in 2020 and 40 TWh in 2030. The Chinese government's objective is to double the number of biogas plants in

China from over 40 million plants (year 2010) to over 80 million plants. Small household scale plants form the majority of this objective and the number of middle-sized farm scale plants or large industrial plants is 16,000 plants (Suomen Biokaasuyhdistys 2012).

7.2.5 Fuel Cell Cars

Nissan Motor Co. is developing a system that will power vehicles with electricity generated from bio-ethanol. The carmaker plans to introduce the powertrain for fleet sales by 2020. The ethanol-powered vehicle will have a driving range of more than 600 km, similar to gasoline-engine cars. Unlike conventional fuel-cell vehicles that use a special tank for hydrogen, Nissan's system will utilize liquid fuel and a conventional tank, and will generate hydrogen through reformation of pure ethanol or ethanol-blended water. It then uses a solid oxide fuel-cell system to generate power from hydrogen and air. According to Nissan its bio-ethanol fuels, including those derived from sugarcane and corn, are widely available in countries in Asia, North and South America, and the vehicles will have running costs that will be on par with electric vehicles (IndustryWeek 2016).

In March 2016, Honda began selling the 2017 Honda Clarity Fuel Cell in Japan. The Clarity Fuel Cell is Honda's latest offering regarding fuel cell vehicles (FCEV) and is the first car that houses its entire drivetrain system and fuel cell stack under the hood. Hence, it can offer a full five-seating system.

Hyundai has planned 1000 Tucson FCEV's to be produced by 2017, and after that the company will look towards mass production. Uncertainty, naturally, is the availability of refuelling stations in different countries.

The Hyundai Tucson FCEV has a 365 mile range, and comparable power to a gasoline engine. The model can achieve a top speed of 100 miles per hour and it takes 12.5 s to accelerate from zero to 62 mph.

Hyundai has contracts for municipal fleet leases in Sweden and Denmark, and after 2015, their goal is to produce 10,000 vehicles. The technology used is proprietary, with hydrogen converted in fuel cell stacks to electricity for the Lithium Polymer batteries that power the motors.

The company expects that world governments will continue further regulation of reduction in carbon output, and independence from fossil fuels (Hydrogen Cars Now 2016a).

The Toyota Mirai is the first production vehicle from Toyota to be powered by the hydrogen fuel cell. The Mirai was first officially revealed in 2014. "Mirai" means "future" in Japanese and expresses Toyota's belief of the future car engine technology. The Mirai was expected to sell for roughly $57,500 in summer 2015 when it was first released in the US. The UK, Denmark and Germany were to start receiving the vehicles in September 2015 and other countries in 2017. Advances in fuel cell technology have greatly reduced the cost of the engine which is just 5% of the cost of the 2008 Toyota FCHV vehicle. The FCV also includes an electric motor which is charged by the power of the fuel cell and acts in the support of the engine when in operation.

Toyota has plans to market the vehicle to the general public as soon as there are hydrogen refuelling stations available in the country. The vehicle was introduced in spring 2015 in Japan (Hydrogen Cars Now 2016b). Biohydrogen could form a future source of traffic fuel.

7.2.6 Circulation of Agricultural Wastes

Microbiota orchestrate any network of reactions that process natural organic substances, their degradation and reuse in soil. Consequently, agricultural production in the long term is dependent on the functionality and "healthiness" of the soil microbial population. Its activity can be monitored in real-time by analysing the soil gas emission, (Fig. 7.7).

Corresponding to the plant kingdom where newly found varieties could constitute a novel basis for food and feed production, key microbial strains have the

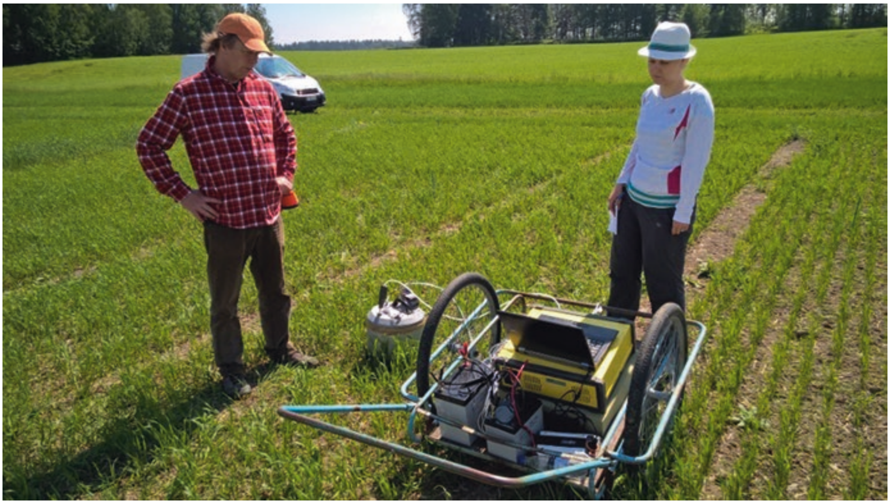

Fig. 7.7 Gas emissions by soil bacteria can be measured by an analyzer that recognizes around 50 of the volatile components. One measurement takes about 4 min. In the picture researchers from the University of Helsinki, Jukka Kivelä (*left*) and Sari Kinnula (*right*) screen the gaseous components emitted from a cereal field which has been fertilized with organic, fibrous substances. Those wastes or side streams derive from the food processing industries, and their effects in restoring the soil functions and microbiota as well as the potential in circulation can be studied by gas emissions. The CO_2 and other gases produced by various microorganisms in soil is then boosting their activity in a positive circle of effects (Hakalehto and Hänninen 2012) (Photograph by Elias Hakalehto)

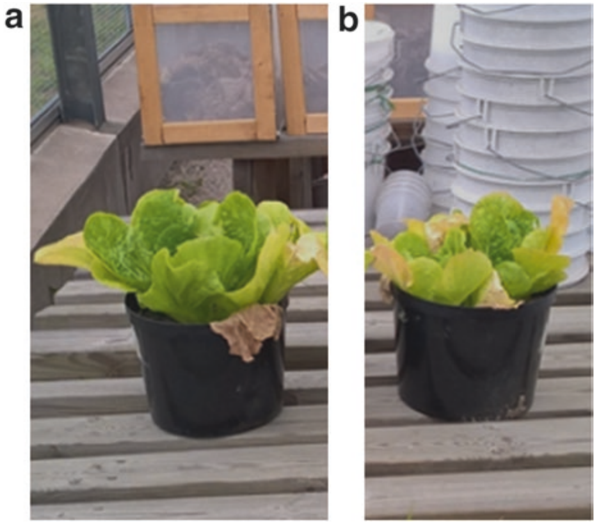

Fig. 7.8 Greenhouse testing of the microbiological supplementation Aurobion® of the Chinese cabbage by a patented process using *Clostridium pasteurianum* strain for boosting the plant growth (**a**). The control without "soil probiotics" on the right (**b**). For further explanation, see the text (Photographs by Elias Hakalehto)

potential for restructuring the soil microbiome (Hakalehto 2016). Such an example is the nitrogen fixing *Clostridium pasteurianum* which has significantly upgraded the crop of Chinese cabbage up to approximately 50%, (Fig. 7.8a, b)

7.2.7 Combined Incineration with Circulation Means

As a classic means for waste disposal and disintegration, controlled combustion has been always a major means for getting rid of unwanted materials.

However, their incineration has also sparked a lot of adverse environmental consequences throughout the ages. For a truly ecological combustion unit with circulation of solid, (Hakalehto and Ojala 2016) designed a unit with inner recirculation of energy, biomass and carbon. See Fig. 7.9.

7.3 Perspectives from the EU Down to National and Regional Level

The perspective towards waste has changed radically during the past decades. During the 1960s the focus was on landfill waste, during the 1980s on ravaging with mass incineration, whereas in the 2000s the focus turned to recycling, source separation, to waste priority order as well as to producer responsibility. Nowadays, the focus is in recycling economy, closed loop, from consuming to using as well as in new technologies and service models. Also, the focus is on sustainable and smart

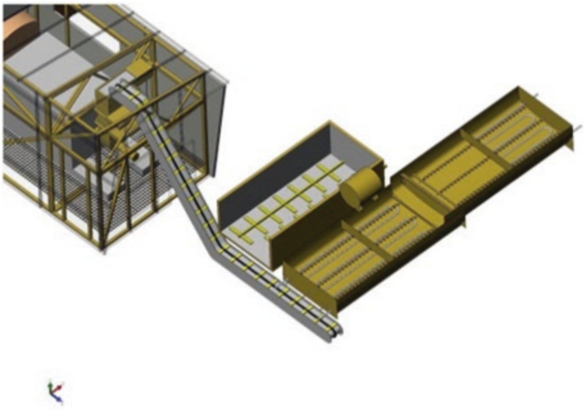

Fig. 7.9 The integrated solution for circulating biomass substances and gas emissions in a combustion unit with a bioprocess treatment for improving the incineration or its alternative uses within one waste treatment plant (Hakalehto and Ojala 2016) (Drawing by Nordautomation Oy)

use of limited natural resources. The aim is to get upwards in the waste priority hierarchy (Hannula 2016)

7.3.1 EU Waste Framework Directive

EU Directive 2008/98/EC (Waste Framework Directive) sets the basic concepts and definitions related to waste management, such as definitions of waste, recycling and recovery. It explains when waste ceases to be waste and becomes a secondary raw material (so called end-of-waste criteria), and how to distinguish between waste and by-products. The Directive lays down some basic waste management principles: it requires that waste is managed without endangering human health and harming the environment, and in particular without risk to water, air, soil, plants or animals, without causing a nuisance through noise or odours, and without adversely affecting the countryside or places of special interest. Waste legislation and policy of the EU Member States shall apply a priority order in accordance with the waste management hierarchy (Fig. 7.10):

The Directive introduces the terms “polluter pays principle” and the “extended producer responsibility”. It incorporates provisions on hazardous waste and discarded oils, and includes two new recycling and recovery targets to be achieved by 2020:

- 50% preparedness for re-use and recycling of certain waste materials from households and other origins similar to households, and
- 70% preparedness for re-use, recycling and other recovery of construction and demolition waste.

The Directive requires that Member States adopt waste management plans and waste prevention programmes (European Commission 2016a).

Fig. 7.10 EU Waste management hierarchy (EU Commission 2016a). http://ec.europa.eu/environment/waste/framework/

An example re-use is a Finnish office furniture retailer Martela Plc that has a Waste Nothing -slogan to express that usable furniture does not belong in a landfill. In their outlets they sell high quality used and reconditioned office furniture in parallel with new ones (Martela 2016).

7.3.2 The EU Circular Economy Package

The European Commission adopted a Circular Economy Package in December, 2015. The package includes revised legislative proposals on waste to stimulate Europe's transition towards a circular economy which will boost global competitiveness, foster sustainable economic growth and generate new jobs.

The Circular Economy Package contains an EU Action Plan for the Circular Economy with measures covering the whole cycle: from production and consumption to waste management and the market for secondary raw materials. Thus, it will contribute to "closing the loop" of product lifecycles.

The revised legislative proposals on waste set clear targets for reduction of waste and establish a long-term path for waste management and recycling. Key elements include:

- A common EU target for recycling 65% of municipal waste by 2030;
- A common EU target for recycling 75% of packaging waste by 2030;
- A binding landfill target to reduce landfill to maximum of 10% of municipal waste by 2030;
- A ban on landfilling of separately collected waste;
- Promotion of economic instruments to discourage landfilling;
- Simplified and improved definitions and harmonized calculation methods for recycling rates throughout the EU;

- Concrete measures to promote re-use and stimulate industrial symbiosis — turning one industry's by-product into another industry's raw material;
- Economic incentives for producers to put greener products on the market and support recovery and recycling schemes (e.g. for packaging, batteries, electric and electronic equipment, vehicles) (EU Commission 2016b).

The business potential based on resource efficiency and circular economy is huge, as e.g. in the US, up to 90% of raw materials used in production still end up as waste (McDonough and Braungart 2002).

7.3.3 Finnish National Waste Plan

Finnish National Waste Plan until 2022 is one example of implementing EU targets in a Member State. The plan will be implemented in 2017. In Finland, there are challenges with long distances and insufficient resources for official supervision. Moreover, research and experimental activity are desired. The National Waste Plan has set the targets and measures until 2022 and contains a plan for preventing waste generation. The Finnish Government has a target that circular economy will breakthrough. The objectives are:

- Waste management is part of Finnish circular economy,
- Valuable recycling material is also collected in small concentrations, such as E-waste,
- Hazardous substances are safely taken out from the cycle,
- High quality research and experimental activity is performed in the waste sector.

Priorities for objectives and measures are:

1. Construction and demolition waste, including wastes from earth construction,
2. Biodegradable waste and nutrient cycle, including sludges,
3. E-waste,
4. Municipal solid waste (Laaksonen 2016).

7.3.4 Ban for Landfilling of Organic Waste

As an example of one of the above mentioned sectors in waste management, a ban for landfilling of organic waste came in force from the beginning of 2016. Waste cannot be landfilled to a conventional waste landfill if the waste's total organic carbon (TOC) or loss on ignition (LOI) exceeds 10%. This is a very tough ban for the Finnish waste management industry and the first experiences are now being gained regarding coping with it.

This ban does not concern:

- Fly ash and bottom ash from energy production and waste incineration when solubility is low enough,
- Contaminated soil when placed apart from other wastes,
- Dead animals,
- Soda precipitates and deinking sludge,
- Gypsum based wastes and stable inert wastes.

Based on a query to environmental inspectors in Finland (Tukiainen 2016) the wastes that are problematic in terms of the ban are:

- Wastes from sand separation wells,
- Various special wastes from industry,
- Wastes from social and health care services such as tissues and cutting and sticking wastes,
- Wastes from fires,
- Screening wastes from wastewater treatment plants,
- Reinforced plastics and fibres (glass, carbon and aramide),
- PVC (polyvinylchloride),
- Part of construction wools,
- Roofing felt.

If waste has been pretreated and it has been reliably shown that there is no other treatment available, an exception has been possible to be permitted. This exception has been used in many cases (Tukiainen 2016).

7.3.5 A Municipalities' Joint Waste Management Authority

As an example of the organizing waste management authority's task, we used the municipalities' joint waste management authority of Savo-Pielisen jätelautakunta (Waste management board of Savo-Pielinen) that covers a wide area in the Eastern part of Finland and has been described by Pöntinen (2016). It has the same operations regime as the regional waste management company Jätekukko Ltd., but has different tasks. The city of Kuopio is the largest of that region, and the board is part of Kuopio's administration. Taking care of authority duties, however, is independent from all the other responsibilities of the member municipalities. The costs are covered with waste fees. The tasks of the regional waste management board are:

- Gives binding waste management stipulations which implement the Waste Act in a way that takes into consideration local conditions. Stipulations are prepared in co-operation between municipalities, regional waste management company and environmental protection authorities. During preparation transportation entrepreneurs, citizens and other stakeholders were heard.
- Defines principles for waste transportation and waste fees.
- Monitors the implementation of waste legislation and stipulation.

- Launches own waste political programme.
- Approves the service level of waste management in the region in the form of which services are offered to citizens.

Connecting to the waste management system can be done in various ways (Pöntinen 2016):

- House-specificly,
- Jointly among nearby estates,
- Using regional collection point for single houses and semi-detached houses in suburban areas,
- Through centralized waste collection systems like tube collecting system,
- Through block-specific deep collection system.

7.4 Statistics of Waste Resources Globally and Examples from Finland

7.4.1 Global Statistics of Waste Amounts

Large amounts of energy and resources have been consumed following rapid economic growth, urbanization and the widespread improvement in living standards.

The United Nations' Environmental Programme UNEP (2015) compiled a Global Waste Management Outlook in 2015 and here we use some selected data from that piece of work. UNEP reports that providing a global overview of total waste generation with sufficient accuracy is almost impossible to achieve. Existing data generally refer to municipal solid waste (MSW). Wider data on waste from different points in the material and product life-cycle exist especially in OECD countries. Therefore, these pieces of data are used as a "proxy", showing the relative quantities of waste from different sources (Fig. 7.11). All data exclude agricultural and forestry and mining and quarrying wastes. An estimate of waste from a broad range of municipal, commercial and industrial sources is 3.8 billion tonnes per year (UNEP 2015).

In principle, it is possible to attempt the extrapolation from the OECD data in the figure above to estimate total worldwide waste generation. This kind of extrapolation is facilitated by the availability of waste data for Russia and China and some other non-OECD countries. Extrapolating from the database prepared for the GWMO to estimate 2010 worldwide MSW generation results in an estimate of around two billion tonnes per year. On the other hand, the World Bank (2012) reports that the global MSW amounts to 1.3 billion tonnes per year and is estimated to increase up to 2.2 billion tonnes by 2025. In any case, the global annual municipal solid waste amounts are huge and there lies enormous potential for utilization. It is also reported that MSW generation levels are expected to double by 2025. The higher the income level and rate of urbanization, the greater the amount of solid waste produced. OECD countries produce almost half of the world's waste, while Africa and South Asia regions produce the least waste (World Bank 2012).

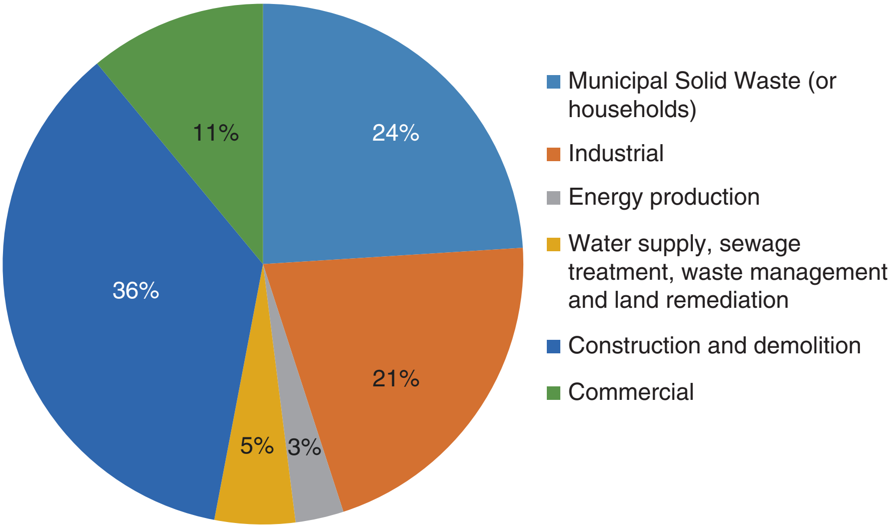

Fig. 7.11 Relative quantities of waste from different sources in the material and product life-cycle (Data from UNEP 2015)

For the other waste streams, extrapolation is even more challenging. Based on the available information, the best 'order of magnitude' estimate of total "urban" waste generation worldwide for the municipal, commercial and industrial wastes, including construction and demolition (C&D) waste comparable to the data indicated for the OECD in the figure is in the range of 7–10 billion tonnes per year (UNEP 2015).

Municipal Solid Waste generation rates vary widely within and between countries. The generation rates depend on income levels, socio-cultural patterns and climatic factors. UNEP (2015) has reported a strong positive correlation between waste per capita and income levels per capita. The median generation rates in high-income countries are about six-fold greater than in low-income countries. There can also be considerable variation within countries; in Brazil, for example, the amount ranged from 310 to 590 kg per capita per year in 2012 according to annual reports on Brazilian waste statistics.

Despite the high variability and low reliability of source data, UNEP (2015) reports some interesting patterns between average waste compositions in relation to the countries' income level:

- A major difference is in organic fractions, which are significantly higher in middle- and low-income countries (averaging 46–53%) than in high-income countries (averaging 34%).
- The percentage of paper waste appears to be proportional to income levels, rising from 6% in low-income countries, through 11–19% in middle-income and 24% in high-income countries.

- Although plastic levels appear generally high, they do not show as much dependence on income level as might be expected, with the averages for all income categories ranging from 7–12%.
- Levels of other 'dry recyclable' materials, including metals, glass, and textiles, are all relatively low.
- MSW now increasingly contains relatively small amounts of hazardous substances.

Waste composition affects the physical characteristics of the waste, including density, moisture content and calorific value, which in turn affect waste management and the choice of technology for collection, treatment and the so called 3Rs: reduce, reuse, recycle. For example, the ash content of MSW in high-income countries has decreased over the last 50 years, while the content of paper, plastics and other packaging materials has increased, significantly reducing the bulk density and increasing the calorific value.

In Japan, for example, 48 million tons of MSW were generated in 2008, which represents a gradual decrease from the 55 million tons generated in 2000. This is a consequence of the adoption of the 3R strategy as well as stagnant economic growth (Takaoka et al. 2013).

Overall, waste generation per capita has risen markedly over the last 50 years. Due to the strong correlation with income level one can assume that, unless specific waste prevention measures are taken, per capita waste generation levels in the current low- and middle income countries will increase as their economies continue to develop and gross national income (GNI) levels rise.

Hoornweg et al. (2015) have projected MSW generation in different regions per capita forward to 2100. According to UNEP (2015) any projection beyond 2050 becomes extremely speculative. It should be interpreted rather as a scenario of what might happen under a particular set of assumptions, than a forecast. High income and OECD is projected to develop from c. 880 kg/person/year down to 730. Sub-Saharan Africa, on the other hand, is projected to develop from ~220 kg/person/year up to 510. There would still be a clear gap between these two, but dramatically less than nowadays. All the other country groups in the world are between these extreme figures and a rise is projected for all of them between 2010 and 2100 (Hoornweg et al. 2015).

7.4.2 Municipal Solid Waste

Municipal Solid Waste comes from households, commerce and public services. Industry as well as construction and demolition waste is not included in this definition. For example in Finland, MSW generated 2.3 M tonnes in 2014 which totalled 481 kg per capita per year. According to EU Circular Economy Package, 65% of MSW shall be recycled by 2030 and a maximum of 10% can be landfilled in 2030. This means a challenge for Finland as nowadays 33% is recycled, and on the other hand, a lot of waste incineration capacity in Finland was invested recently. Since waste incineration plants were invested for municipal waste incineration a concern arose among the Finnish waste sector whether there is sufficient incineration capacity available for industrial wastes (UNEP 2015; Laaksonen 2016; EU Commission 2016b; Tukiainen 2016). However, keeping in mind the priority order, waste recycling would be more prioritized than energy recovery.

The Finnish Waste Plan proposed to prioritize source separation enhancement within commercial and public services sectors as well as in urban areas. Preparation for reuse and recycling are the focus in line with the EU priority order. For example packages should be recycled as packages and products as products. Producer responsibility systems are a key tool for this.

An example of waste bin stipulations in Savo-Pielinen area in Finland (Pöntinen 2016):

- Mixed waste bin must be at all estates and from this bin waste is directed to energy recovery. Inert wastes are not allowed in principle.
- Recyclable wastes. Most of these are packages which belong to the so called producer responsibility system. Regional waste management company may complement the collection of these.
- Bins for biowaste and cartonboard must be in estates with at least five apartments. Biowaste bin must also be present if it is generated over 50 liters per week.
- Bins for metal and glass must be in estates with at least 20 apartments.
- Plastic bin must be in estates with at least 40 apartments.
- Paper bin must be in every estate except one-family houses and estates in sparsely-populated areas.
- Energy waste (recovered fuel, REF) must not be collected separately.

Fractions that can be recycled must not be directed to incineration. Other wastes are collected to mixed waste and transported further to incineration.

Uniform and well functioning bin equipment enables efficiency, working safety and better service. Frequent enough emptying is addressed. In some cases emptying intervals are prolonged in order to encourage prevention and separation of waste and to cut unnecessary costs of customers. An example of waste bins in Barcelona is given in Fig. 7.12.

7.4.3 Example of a Producer Responsibility System

Suomen Pakkauskierrätys RINKI (Finnish Packaging Recycle Ring) is a non-profit service company owned by industry and commerce. The company takes care of cartonboard, metals, glass, wood and plastics. Industries and commerce which have annual turnover over 1 M € must belong to the company or they would need to organize about 2000 waste collection points themselves, so all industrial and commercial companies in Finland have joined the company. They have transferred their

Fig. 7.12 Waste bins in Barcelona, Spain (Photograph by Ari Jääskeläinen)

legislation-based responsibility to this producer responsibility community and there are 4200 companies as members. There is also a separate producer responsibility community for waste with deposit in Finland.

There are 1.8 M tonnes per year of packages produced in Finland from which 1.1 M tonnes (60%) are reused or recycled by the packaging industry itself. The amount of packaging waste is correspondingly 0.7 M tonnes, from which is directed to:

- Recycle 56%,
- Energy recovery 35%,
- Landfill 7%.

Term Producer Responsibility was invented in Sweden in 1997. In Denmark and Switzerland, for example, there is not a Producer Responsibility Law whereas in Norway the system is voluntary. In Finland, the producers take care of the reverse logistics system and waste management utilities provide the complementary services. Operations are financed with recycling fees. For example, the price of a milk pot contains a recycling fee of 0.5 cents (Koivunen 2016).

The Finnish Government Decree on packaging and packaging waste (2014) stipulates that the collection points must cover the whole country. Cartonboard, glass and metal have to be collected in each suburban area with at least 500 inhabitants. In sparsely populated areas the collection points must be available in line with trade centres, which make up a total of 420 collection points in sparsely populated areas. At least one plastic collection point must be available for a suburban area with over 10,000 inhabitants.

At the moment there are altogether 4400 collection points in Finland, having bins for:

- Fibre in 1850 points,
- Glass in 1850 points,
- Metal in 1850 points,
- Plastics in 500 points and
- Clothes in 2200 points.

In Finland, there are altogether six contractors in collection of producer responsibility waste in RINKI which means that the logistics is very efficient. Various sized bins are scaled to shops with various sizes and they are compatible with the refuse lorries. Intelligent collection equipment enables the functioning logistics. For example, bins send automatic notifications about filling rates (Koivunen 2016).

7.4.4 Metals

Metals are traditionally popular materials to recycle as they maintain their properties much better than many other materials and have economic value in replacing natural resources' consumption. Recycling rates depend both

- On the degree of mixing and
- On the concentration of the target material or element.

In a study of 60 metals (UNEP 2011, see Fig. 7.13), one third have recycling rates greater than 50%. These include aluminium, titanium, chromium, manganese, iron, cobalt, nickel, copper, zinc, rhodium, palladium, silver, platinum and gold. These all are either needed in high concentrations and/or possess a high value. They are very crucial raw materials in nowadays' life.

More than half of the metals have recycling rates of less than 1%. Many of these, such as indium and gallium, are regarded as 'critical materials' or are rare earth metals including lanthanum, cerium, praseodymium, neodymium, gadolinium and dysprosium. These metals are all used in a wide range of electronic products including screens, chips, speakers and microphones as well as in magnets. The concentrations are often very low and the degree of mixing with other elements is very high. These make it very challenging to recycle these critical metals. A major challenge moving forward is to ensure that design for environment (DfE), including dismantling and recyclability is prioritized in these industrial sectors (UNEP 2011).

The periodic table is used above to show 60 metals' global average end-of-life recycling in which the physical and chemical properties that made the material desirable are retained for new use.

Unfilled boxes indicate no data or estimates available or the element was not addressed in the study.

The dynamics of the metal industry is described here with aluminium which is the most used and the fastest growing of the non-ferrous metals. In 2000, China produced 12% of the global aluminium (2.9 million tonnes). By 2011 this rose to 43% (19.4 million tonnes) at the same time that global total grew as much as 80%.

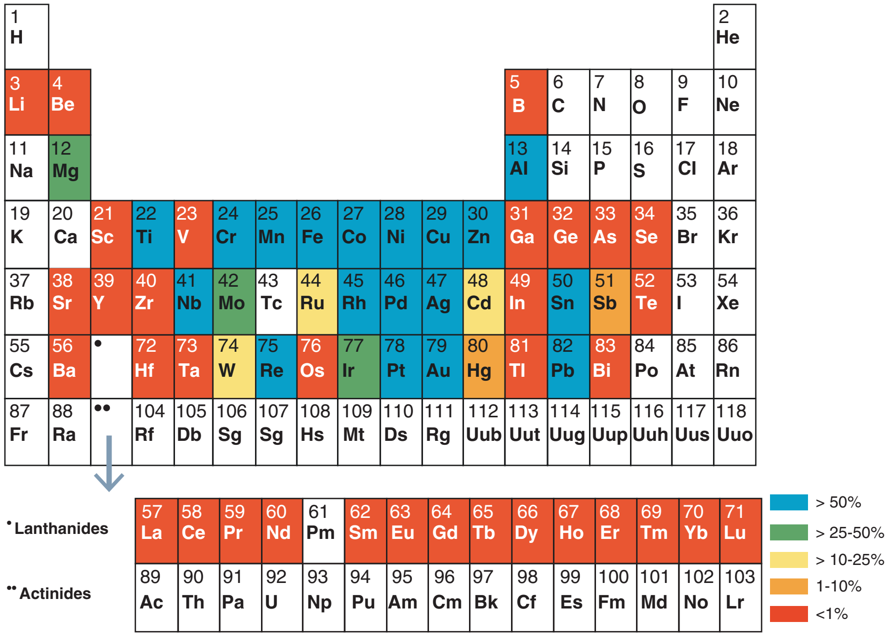

Fig. 7.13 End of life recycling rates for 60 metals (Source: UNEP (2011). Recycling Rates of Metals: A Status Report. http://www.unep.org/resourcepanel/Portals/24102/PDFs/Metals_Recycling_Rates_110412-1.pdf)

During the same period, demand for aluminium scrap increased by 7.4 million tonnes per year. From this increase, China accounts for 85% (6.3 million tonnes). Supply from scrap has not increased at the same pace with the increase in aluminium production. The ratio of scrap used in aluminium production decreased over the period from 31 to 29% (UNEP 2011).

7.4.5 Plastics

Plastics are also very actively used waste material. Global production of plastics increased from 1.5 million tonnes in 1950 to 204 million tonnes in 2002 and 299 million tonnes in 2013. There is a continuing shift of production from the West to Asia, the latter representing more than 40% by weight of world production in 2013. The annual volume of transnationally traded waste plastics (15 million tonnes) represents 5% by weight of new plastics production. There is huge potential to increase the reverse logistics of plastics. Plastic scrap flows from Western countries with established recycling collection systems mainly to China, which receives around 56% weight of global imports. Europe (EU-27) exports almost half of the plastics collected for recycling and 87% of this is directed to China (UNEP 2015).

In Finland, the recycling rate of plastics was 23% in 2013. In the EU Recycling Economy Package the objective for plastics recycling is 55% by 2025 so a major step forward is needed (Laaksonen 2016).

7.4.6 *Paper*

In Finland, there are long traditions for collecting paper waste. After the Second World War it was common for young boys to earn some money by going round and collecting used newspapers from houses and delivering them to paper waste buyers. Since then, Finland has had a high rate of paper waste recycling.

The total world production of paper and paperboard in 2012 was around 400 million tones; 45% was in Asia, 26% in Europe and 21% in North America. Recycled paper and paperboard (known in the industry as 'recovered paper' or 'recovered cellulose fibre') has always been a major raw material for the paper industry. The proportion of recovered paper of the total pulp used in the European paper industry rose from 40% in 1990 to 53% in 2013. This is a major development as at the same time total production in Europe rose by around 50%. Two hundred and thirty million tonnes of recovered paper was collected and consumed globally in 2012 (UNEP 2015).

7.4.7 *Food Waste/Biowaste*

According to 2013 estimates of FAO (Food and Agriculture Organization of the United Nations), approximately 1.3 billion tonnes of edible food per year is lost or wasted. This represents one third of all the food produced for human consumption. This amount of food would be sufficient to provide nutrition for more than 2 billion people, which is more than double the undernourished persons in the world, according to the official FAO estimate (UNEP 2015).

Moreover, the production of this lost food has caused both resource use and environmental impacts for climate, land, water and biodiversity in producing this food. The global greenhouse gas (GHG) emissions, for example, related to food waste were estimated at 3.3 G tonnes of CO_2 equivalent in 2007. The financial loss of food waste in terms of producer prices is as much as USD 750 billion. If we counted in terms of supply chain and market values, the sum would be far greater. The further along the supply chain the loss occurs, the worse its environmental impact, and the financial losses, as more handling and resource input is needed. (UNEP 2015)

These losses occur at different places along the supply chain and the places and the reasons vary a lot between developing countries and developed countries (Table 7.1).

Preventing this wasting would naturally have a great positive effect globally on food security. Food waste could be utilized in various ways:

Table 7.1 Food loss comparison between developing countries and developed countries

	Place along supply chain	Reasons
Developing countries	Almost 80% of the losses in farm and in transportation and processing	The unavailability of selling outlets or inadequate packaging and storage
Developed countries	Almost 80% of the losses in retail, catering and at home	Various reasons including extremely stringent cosmetic standards for fruit and vegetables, relatively low prices for consumers, strict adherence to ‘use by’ and ‘best before’ dates despite inadequate understanding of the meaning of such labelling, lack of knowledge on food safety and ‘use by’ dates set earlier than necessary due to fear of litigation

Data from UNEP (2015)

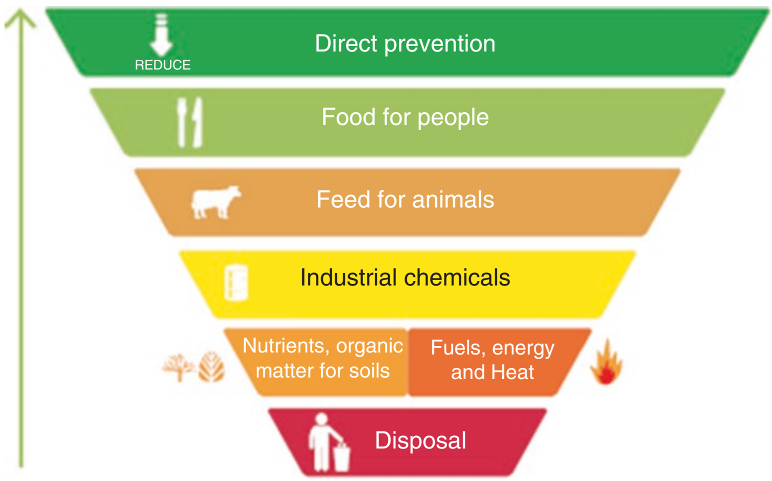

Fig. 7.14 Food waste hierarchy (UNEP 2015)

- Directly,
- Through redistribution to those in need,
- Via conversion to feed for animals,
- Via conversion to industrial chemicals,
- Via conversion to fertilizer or organic matter,
- Via conversion to fuels and energy.

Figure 7.14 illustrates the hierarchy of measures regarding food waste.
The following presents a couple of examples regarding food waste abatement.

Food banks were established all around the world, contributing to food and nutrition security by connecting prospective food waste and people in need. One example is the food bank in Belo Horizonte, Brazil who has been a pioneer in urban governance on food security since 1993. The City Food Bank was established in 2003 with the target to prevent food waste while providing healthy food to those in need. Food is collected from partners including street vegetable markets, green groceries and supermarkets, and then goes through a rigorous process of selection, processing, and storage, with sanitary norms strictly observed. The processed food is distributed to over 100 institutions of City Food Bank register, including day-care centres, homes for the elderly, orphanages and shelters, about 15,000 people receive the help (Rocha and Lessa 2009).

In France, 20–30 kilos of food waste is generated per capita per year, totalling circa 1.3–2 M tonnes per year. The value of thrown away food has been estimated as 12–20 billion euros. In spring 2016, the Parliament voted unanimously on a law which bans supermarkets from wasting groceries that were not sold. Instead, they must take action to decrease food waste. Supermarkets must give unsold but edible groceries to charity, animal feed or for composting. Large supermarkets must make a contract with charity organizations about giving groceries to those in need. The French Government wishes to be able to halve the amount of food waste by 2025 (Guardian 2016).

Silvennoinen et al. (2012) studied the Finnish food chain and found the food loss along the supply chain to be as presented in Fig. 7.15.

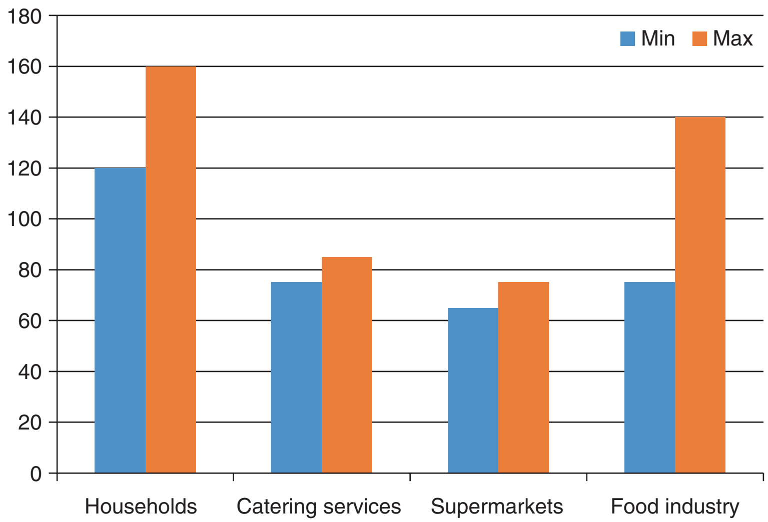

Fig. 7.15 Preventable food waste in the food chain. The total amount is 355,000–460,000 tonnes per annum or 62–86 kilos per capita (Data from Silvennoinen et al. 2012)

In Finland, thanks to the packages, only 2% of food spoils before it reaches the consumers. For example, in Africa this number is over 10% or even tens of percents (Pöntinen 2016).

In the EU separate collection of biowaste will be increased and encouraged. Biowaste will be directed to anaerobic digestion or other treatment systems that promote circular economy. In Finland, the municipal biowastes were treated by (2014):

- Composting 43%,
- Anaerobic digestion 17%,
- Landfill or combustion 40% (Laaksonen 2016).

7.4.8 Example of a Campaign to Enhance Biowaste Separate Collection

In 2003, regional waste management company Jätekukko Ltd. started to deliver biobags for the year's need. The effect was 10 kg per inhabitant from 37 kg per annum to 47 kg per annum. The delivery is still carried out annually, totalling two million biobags per annum. Baskets for collecting biowaste were also delivered.

Based on separation research the composition of mixed waste is such that there is 30% biowaste which totals 12,000 t per annum. In comparison, from the same region 8000 t biowaste is separately collected annually.

Separation has to be easy and the inhabitant must experience that it is useful. Jätekukko held a campaign for men below 35 years. Easiness and meaning were selected as focuses. It was illustrated that 2 kg biowastes give 140 h light with a 7 W energy saving lamp.

An advertisement was directly mailed to 40,000 households, in addition web site, social media and regional television were used. The reach of people between 15 and 34 years was 97% (72,000 persons).

Jätekukko Ltd. tried two different ways to deliver biobags for citizens. One trial was to introduce a rack inside of the waste bin shelter to which the waste lorry driver changes biobag rolls in conjunction with emptying the biowaste bin. The other trial was that citizens could fetch the biobags from supermarket with a special card. For the first trial 92% of respondents used these biobags. The rest of the respondents viewed this as not important or had no room or functionality in their apartment for biowaste separation. Seventy three percent viewed the trial as a functioning one. However, Jätekukko Ltd. concluded that this is not a recommendable option due to hygienic and other practical reasons. In the second option supermarkets were satisfied.

Regarding the potential for the biowaste yield, Jätekukko Ltd. estimated that 1.8 kg/person/week would be possible. In practise the yield has been about 0.4 kg/person/week. The campaign that Jätekukko Ltd. launched in 2015 did not affect to the yield, which shows that it is slow to affect attitudes. Biowaste is regarded as inconvenient so it is crucial to improve the cleanness of the collecting equipment. Jätekukko Ltd. has also marketed options of joint biowaste bins for single houses, which has increased the amount of these by 24% but still the absolute number is very low. This would give discounts in a basic annual waste fee as well as in mixed waste emptying fees as the interval gets longer. On the other hand, many single houses have their own composting equipment (Maunula 2016).

7.4.9 E-waste

Waste electrical and electronic equipment (WEEE), known as 'e-waste', comes from a large variety of electronic products, large equipment (washing machines, air-conditioners, freezers etc.) and small equipment (hairdryers, electric toothbrushes, vacuum cleaners etc.). As a consequence from increased consumer demand, perceived obsolescence, short life cycles of many products, rapid changes in technology and inventions of new electronic devices, WEEE grows fastest among the world waste streams. Many products have not been designed with recycling in mind (Baldé et al. 2015).

According to the estimate of the United Nations University, 41.8 million tonnes (Mt) of e-waste was generated in 2014, a 25% increase from 2010. Waste generation was spread across continents as follows: Asia (16 Mt), Europe (11.6 Mt), North America (7.9 Mt), Latin America and Caribbean (3.8 Mt), Africa (1.9 Mt) and Oceania (0.6 Mt). Europe's per capita e-waste generation is the highest (15.6 kg/person) and Africa's the lowest (1.7 kg/person). Annual generation is estimated to increase up to 50 Mt in 2018 (Baldé et al. 2015). Surely the amount will further increase from that.

In Finland, it is estimated that there is 0.9% e-waste in household mixed waste (Helsinki Region Environmental Services Authority 2012). In the service sector Helsinki Region Environmental Services Authority has estimated the corresponding amounts:

- Supermarkets 0.1%,
- Schools 0.3%,
- Restaurants 0.3%,
- Hospitals 1.9%,
- Offices 0.2% (Helsinki Region Environmental Services Authority 2012).

Therefore, attention should be paid specially in source separation of e-waste in hospitals.

The objective is to prolong the life span of electric devices via better reparability. How can repair and lending culture be made more attractive by means of administration? One option would be to introduce lower value added tax for repairing electric devices (Laaksonen 2016). One of the writers witnessed a situation in which a truck load of computer screens in unopened selling packages were directed to a plant in which e-waste is dismantled for recycling of various metals and other components, such that these products were never used anywhere. The reason might be that the products in question were too old to market as high tech, but surely another solution could have been found to get these products in use via charities, etc.

7.4.10 Textile Waste

In the UK, textile waste is a major problem. Every year an estimated *£140 million worth* (around 350,000 tonnes) of used clothing goes to landfill. The Waste and Resources Action Programme (WRAP) is a registered UK Charity and among other activities it leads the Sustainable Clothing Action Plan (SCAP) with the ambition to improve the sustainability of clothing across its lifecycle. The action plan brings together industry, government and the third sector and works across the clothing lifecycle, identifying improvement actions to most reduce the environmental impact, and has agreed to the SCAP 2020 targets (WRAP 2016).

In Finland, textile waste amounts to 54,700 tonnes per year (Laaksonen 2016). On the contrary, in 2015 the Finnish Red Cross sent from its logistics centre over 161 t clothes to Mongolia, Kirgisia, Ukraine, Tadzhikistan and Kazakhstan, and in Finland clothes were delivered to over 10,000 asylum seekers in the Red Cross reception centers. There would be huge potential to increase recycling clothes as products for these uses (Finnish Red Cross 2016).

7.4.11 Mixed Waste

Mixed waste is a term widely used in Finland. Typically municipal and commercial wastes, after source separation of recyclables and biowaste, are mixtures of plastics, metals, glass, biodegradable waste including paper and textiles along with other nondescript wastes. Mixed waste was generated in Finland 1.35 M tonnes in 2014. The composition of mixed waste is:

- Plastics 19%,
- Cartonboard and cardboard 10%,
- Textiles and shoes 6%,
- Metal 3%,
- Glass 2%,
- Wood 1%,
- Mixed 15% (Jätelaitosyhdistys 2016).

So in fact, only 0.15 × 1.4 M tonnes = 210,000 tonnes is truly mixed waste annually. There is clearly room to improve the source separation of recyclables.

According to the Finnish National Waste Plan there should be less than 10% biowaste in the mixed waste. Biowaste lowers the heating value of the mixed waste. On the other hand nutrients will not return to nutrient cycle if biowaste is incinerated. There is nowadays 36% (493,000 tonnes per year) biowaste in the mixed waste. This has been 90 kilos per capita per annum. The objective would be 17.9 kg. According to a regional waste management company Puhas Ltd. from the eastern part of Finland there is even 49% biowaste in the mixed waste during winter time. On the contrary, there is an obligatory separate biowaste collection or composting in the central part of Finland. That is also the best region in Finland with only 19% biowaste in mixed waste. Still, there is also some room for improvement reflecting the objective (Laaksonen 2016).

7.4.12 Construction and Demolition Waste

Construction and demolition (C&D) waste is generated during the construction, renovation or demolition of buildings, roads, bridges and so on. These activities typically generate large quantities of waste, although often data on C&D waste are not collected as part of the activity or in a consistent way, so most published estimates need to be carefully interpreted. Eight hundred and twenty one million tonnes of C&D waste was estimated to be generated across the EU in 2012, 77 million tonnes in Japan, 33 million tonnes in China and 17 million tonnes in India (all in 2010). From the total waste generated, C&D waste often represents the largest portion. For example, of the all urban waste generated in OECD countries C&D waste represents 34%. The volume of C&D waste is also sharply increasing in line with the trend of infrastructure development all around the world (UNEP 2015).

C&D waste contains a high proportion of inert materials (e.g. concrete, masonry, asphalt), and also wood waste, metal, glass, gypsum and plastics as well as hazardous substances such as treated wood, lead paint and asbestos. Due to the variety of materials, it would be important that the C&D waste is segregated at source, with each stream managed as required. In practice, there is usually a shortage of room at construction sites for containers for different types of wastes. Some waste management companies offer C&D waste separation at their waste management sites as a service for construction companies (UNEP 2015).

Waste management controls were first introduced in the 1970s and at that time the illegal dumping of C&D waste was widespread. In many developing economies illegal dumping is still a problem, or even epidemic, like it is in India for instance (Centre for Science and Environment 2014). The management of C&D waste is a critical part of sound waste management since illegal dumps can be like ‘magnets,’ increasing probability of municipal solid waste or even hazardous waste being dumped, exposing serious health and environment risks (UNEP 2015).

The primary motivation in the construction industry for increasing reuse and recycling is cost control, as these practices will reduce costs through reduced disposal costs, decreased purchasing costs for new materials, and increased revenue earned from the sale of materials (UNEP 2015). Also, working safety is enhanced when the construction site is in order in terms of wastes.

Countries recycle C&D waste with an enormous range. A ‘best estimation’ of the EU average was given for 2008–2009 as 30–60%, with EU countries reporting recycling and recovery rates over 90% on the one end and 10% on the other end (European Commission 2016c).

EU has set an objective of 70% recycling rate by 2020; whereas, nowadays the recycling rate in Finland is 26%. Construction of new buildings yields 16%, renovation 57% and demolition 27% (Statistics Finland 2016). The trend in new building construction is that the waste amount decreases in relation to the built square meters. Nowadays, the total waste amount from a new building in Finland is 22 kilos per square meter. From this:

- Wood 27–30%,
- Mineral waste 14–26% (concrete and brics),
- Mixed waste 40–51%.

Overall, over 2 M tonnes C&D waste is generated annually without loose soil; 40% of this is wood and 31% stone and concrete.

Unfortunately, there is no obligation to report C&D waste streams in Finland so the monitoring authority in the location does not receive information about these streams. Part of the stream goes through waste management centres which are monitored and which report the waste amounts they receive. However, it is not known how large proportion goes through them. There has to be a transfer document in place in connection to the batches of C&D waste. For example, it is not allowed to introduce concrete to forest roads. The question is whether companies are ready to pay for C&D waste treatment or not (Koponen 2016).

According to Finnish Waste Law the following C&D fractions must be recycled:

- Concrete, bricks, tiles etc. mineral waste,
- Gypsum containing waste,
- Wood waste (without impregnation),
- Metal,
- Glass,
- Plastics,
- Paper and cartonboard.

Many of them are appropriate to be separated in collection equipment in case there are larger amounts. There would be need for separation instructions for various phases of the construction work as the composition of waste varies a lot regarding the construction phase.

Examples of C&D waste utilization from Finland:

- Roofing felt for asphalt raw material,
- Demolition windows for heat insulation such as foam glass,
- Clean wood and impregnated wood are utilized in energy production,
- Pallets for repair with an automatic, robotized production and inspection line,
- Wood plastic composite production being tested,
- Demolition concrete may be used in earth construction such as roads, storage fields and courtyard construction as well as the same locations as contaminated soil.

Mixed C&D waste can be separated in a waste management plant with a digger as a rough pre-separation for removing metals to recycle. Mechanical separations involve crushing, sieving, wind separators, air classifiers and removal of metals. In Finland, mixed C&D waste is separated in waste management centres. At best 85–90% of C&D waste is obtained for recycling and energy recovery.

A modern option is near infra red (NIR) separation units which use NIR spectrum for separating desired fractions out from the waste stream, such as wood, cardboard, paper and mineral material. NIR cannot separate plastics, and thus another technology is needed.

For construction components their trading occurs through a web-based market place and eco-markets are used, too, but transportation of large items might be a problem. Used building components such as doors have currently poor demand and low price in Finland (Koponen 2016; Hannula 2016).

Tukeva work training foundation's Ekoraksa 2 project (Eco construction site 2) provides help for work-intensive demolition. Persons that are long-term unemployed and in a weak situation regarding the labour market are employed in collection and separation of excess materials from construction, detachment and separation of materials from buildings that will be demolished, renovating construction materials and supplies for reuse as well as for selling recycled supplies. An objective is to create permanent jobs to various phases of recycling of construction materials and supplies as well as to direct these persons to vocational education or open labour markets (Tukeva 2016).

7.5 Conclusion

Human societies and their economic structures consist of overlapping networks, which resemble the food-chains and the interactions of various biological organisms in Nature. Seeing the substrate flow as an ecosystem could essentially help us in tracking the movements of biomasses and other disposed side streams. The goal should be to avoid accumulation of biowastes, or any biodegradable wastes and the replacement of landfills, emissions and leakages by a pattern of reuse and circulation. This effort needs understanding of the microbiological dimensions and microbiomes, since they form the powerhouse of recirculation.

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Chapter 8
Energy, Different Forms

Erik Dahlquist

8.1 Production/Conversion

We talk about energy production, although thermodynamic law says this is not possible. So in reality, chemical energy is converted into heat and power by combustion in boilers, and steam drives a turbine. Wind, wave and hydro power is mechanical energy transferred into electric energy, and solar power radiation from the sun produces electricity using semi-conductors.

8.1.1 High Temperature Gasification

Gasification is partial combustion. It is a process where enough oxygen is added to get a high temperature, and then the temperature is kept at around 800–900 °C; at least when biomass is the fuel. Instead of only obtaining water and CO_2 you also get H_2, CO, CH_4 as well as tars. In China and South Africa, coal gasification commonly produces different chemical products that otherwise would need to be imported. Now, they can use domestic coal to produce these chemicals. In South Africa, Sasol operates the gasification plants; while there are many different plants in China, where approximately 15% of all coal is gasified.

In Scandinavia, biomass is primarily gasified and normally in connection with production of ammonia, which is one of the chemicals also produced in China, but from coal.

In Finland, there were a couple of plants, but it has been difficult to get economically competitive prices against coal or oil as fossil alternatives. In 2015, a waste gasification plant was erected in Lahti. The capacity is some 160 MW thermal. A feature

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Springer International Publishing AG 2017
E. Dahlquist, S. Hellstrand (eds.), *Natural Resources Available Today and in the Future*, DOI 10.1007/978-3-319-54263-8_8

here is to use ceramic filters of a new type, produced in Finland. The filters are non-woven materials similar to textile filters used in baghouses. The plant has now been in operation for more than a year and the results seem to be acceptable, although the filters have burnt a couple of times.

A similar plant was planned in Vasteras but was never erected as METSO got more favorable conditions by way of government support in Lahti, which was not possible in Vasteras. According to the economic calculations, Malar Energy would have half the cost adding a gasifier to an existing coal fired boiler and burning the gas in this, compared to building a completely new waste incinerator.

Complementing existing boilers with gasifiers is probably the economically most competitive solution in the future. Produced gas can be combusted in boilers or gas turbines, but separation of gas components using membrane filtration can be an alternative. Then hydrogen and/or methane can be extracted and sold as more refined products. Hydrogen can be used for hydration of biodiesel or other liquids with oxygen, or directly used in fuel cell operations. Methane can be introduced into a natural or biogas net, and used as a complement. This should be a first system solution, as large systems for natural gas already exist in many countries. In Nanyang, the company Tianguan Bioethanol group produces some 650 000 m^3 bio-ethanol and 50–150 million m^3 biogas in a total of 250 000 m^3 reactor volume. The gas is dried, and then introduced into the NG-net. Since the gas is only used for domestic applications, mostly cooking food, it does not matter too much that there is some 35% CO_2 in the gas. By mixing with NG the percentage is further reduced. In China, the production of biogas is increasing fast, but high temperature gasification still mostly uses coal as the fuel. In the future we can expect an increase.

Biorefineries based on cellulosic material so far primarily use low temperature processes combined with digesters for further processing of the liquors produced. Black liquor gasification though could be used as an alternative. Methane, methanol, ethanol, vanilla etc. can be produced as well as tall oil and products produced from the basic chemicals. Alimuddin et al. (2010), Kumar et al. (2009) and Arena (2011) made a review of this, while Cheremisinoff and Rezaiyan (2005) wrote a book describing the basics of gasification.

Naqvi et al. (2010, 2012a, b, c) investigated black liquor gasification, which has the potential to replace recovery boilers in the pulp and paper industry. This can give high efficiency with respect to electricity from the heating value of black liquors, up to 38% in a combined cycle with both gas turbine and steam turbine, although the fuel is very poor with 70% DS containing roughly half inorganic slats and the rest mostly lignin. The actual process including direct caustization has been described by Dahlquist and Jones (2005). Andersson and Harvey (2006) also studied black liquor gasification systems, but with a focus on hydrogen production; Bergelin et al. (2002) focused on methanol production. Consonni et al. (2009) looked at production of different chemicals in a biorefinery approach. Kreutz et al. (2008) also showed this by combining with a Fischer-Tropsch process to produce hydro carbons. Larsson et al. made an economic assessment (Larson et al. 2000) and Kirkels and Verbong (2011) discussed why biomass gasification has not “taken off”.

To increase the conversion rate in gasification Tao et al. (2015a, b) investigated the positive impact of an electric field while Ptasinski (2008) studied how to improve thermodynamic efficiency Thorin et al. (2011a, b) have investigated how the gas quality differs between gasifying black liquor respectively wood pellets. In the first case the amount of H2 is very high, while it is low in comparison to CO in the case of wood pellets. The CH4 is similar in both cases. Palonen et al. (2006) has described the Foster Wheeler gasification more indetail while Pascual and Saul (2008) have described the biomass resources in Europe as well as the pressurized CFB process developed in Varnamo and known as the Chris gas project.

8.1.2 Biogas Production

Biogas is the product from anaerobic digestion of organic material, performed by microorganisms. The major products in the biogas are methane (50–65%) and CO_2 (35–50%). Also, small amounts of, e.g. H_2S, NH_3 and higher hydrocarbons are produced depending on the composition of the substrate.

Biogas production is very common in many countries, and there is an estimate that there are more than 20 million small production units for single households or a group of households in China.

In Germany, there are many plants at single farms where the gas normally is used to produce electricity. In Sweden, there are many biogas production units for production of methane, which is upgraded and then used for vehicles. Normally, CO_2 is scrubbed away using pressurized water to absorbe CO_2, and the water is then regenerated in a stripper by releasing the pressure whereby the CO_2 is released. Here, most of the gas is produced from organic household waste. Ahrens and Weiland (2007) studied biogas potential for both German crops and household waste.

In biological waste water treatment plants globally, sludge is also digested to produce methane, which is then often combusted to produce heat and/or electricity. Since there are many biological waste water treatment plants globally this is very important, as otherwise most of the material would be decomposed at some waste pit, where methane is formed and released to the atmosphere, causing global warming effects. The situation is the same for household waste, which normally is deposited at waste pits, where methane evaporates into nature. By collecting methane and combusting it, we can both utilize the methane and avoid global warming effects.

In a study made in Bolivia, it was difficult to motivate production of methane for combustion, as methane is very cheap there, only 0.15 €/m^3. In Scandinavia, the methane is sold after enrichment from biogas for 1–1.3 €/m^3, or almost ten times more (Lönnqvist et al. 2013). This is because there are huge amounts of fossil methane in Bolivia and the concern about global warming has not been prioritized by the government (although cities like La Paz have been concerned). Instead, it is the residue after the digestion that is most valuable, since Bolivia has low quality soil in the mountain areas around La Paz and El Alto. The soil enhancement effects are strong, and therefore the residue valuable, which pays for the digester handling. Still, it makes sense to use the gas produced in nearby ceramic industries close to where waste is sorted and managed.

We already mentioned the large bioethanol factory in Nanyang, where 20 reactors with 10 000 m^3 reactor volume operate at thermofilic conditions, followed by a second step with a mesofilic reactor of ~50 000 m^3 reactor volume giving some 50–150 million m^3 biogas. The goal is to reach 150 million when the system is optimized. Of this 35–45% is CO_2, which is not removed, but principally could be if there were economic incentives for it. Alongside the 20 million small scale reactors, there are also some 10 000 larger reactors. Although there are still relatively few very large systems, plans exist to build more. The center for this today is in Henan province, where the major agricultural production takes place in China.

A number of factors influence the yield and capacity of biogas fermenters. Thorin et al. (2011a, b, 2012) investigated factors like viscosity, stirring/mixing and pretreatment of the substrate with mechanical disruption. The viscosity is important in relatively concentrated sludge, around 8–12%, but not if dilute (<4%). Mixing is also important in the same range of more concentrated sludge, but not so much in dilute. Pre-treatment has given significant enhancement as well. The effect of mixing was studied more in Lindmark et al. (2014). Lin et al. (2011) studied the impact of temperature, which is another important variable. For biogas production, thermofilic conditions (approximately 55 °C) normally give better yield than mesofilic (approximately 35 °C). The thermofilic condition also kills off most bacteria that can infect humans, and thus has a hygienic effect. If we increased the temperature even further to some 70 °C after the fermentation, the hygienization becomes quite good, and the residue can be recycled to farmland areas without risk of causing infections in crops.

8.1.3 Biodiesel

Biodiesel is a liquid fuel that has properties very similar to fossil diesel fuel. Principally, it could be oil like rape seed oil, but as the viscosity of this normally increases a lot when it is cold, the oil is modified by reacting with methanol or ethanol to form methyl or ethyl esters. These esters have better viscosity properties, but also create large amounts of glycerine or glykole. The catalyst for the reaction is normally NaOH or KOH solutions, which has to be separated after the reaction together with water. This is important as small amounts of alkali salts can cause severe corrosion problems in engines of all kind. Thus, normally the product is washed with water to removed salts. As an alternative, other types of solutions for catalysts are tested to diminish this problem.

Fatty acid esters (FAME = Fatty acid methyl ester) is the most common diesel product from renewables. Other liquids can be methanol and ethanol mixed in with diesel, or tall oil separated from the black liquor in pulp plants. This product can also be used in normal power plants or even in other types of vehicles like ships and aeroplanes. In the future, we can probably also obtain hydrated product that increases the heating value per m^3 or ton of fuel, compared to what we have with FAME.

Many different types of biomass are used for production of bio diesel, like Jatropha, rape seed oil, spent oil from restaurants, oil from green micro algae etc.

8.1.4 Ethanol

Microorganisms are usually used for biogas production. However, either microorganisms or Saccharomyces, yeast, can be used for ethanol. The yeast normally ferments sugar into ethanol and CO_2, and after separating the solids by filtration we drink the filtrate as beer or wine, depending on what strains and raw material were used for the fermentation.

If we distill the product we can achieve very pure alcohol, primarily ethanol. If we use different bacteria, like some Clostridia, we can also produce butanol and other alcohols. 2,3-butandiol for instance can be used as a base chemical for production of different kinds of more complex chemicals.

While earlier glucose was used as the substrate, now with selected strains of Saccharomyces, pentoses can also be used for production of ethanol. This has become very popular to increase the yield from a certain amount of substrate. However, there is a cost to manufacture the enzymes that convert the pentoses, which makes it less economically interesting (Chandel et al. 2011). Pentoses are produced when, e.g. wood (Amidon 2006) is pre-treated with steam explosion, enzymes (Alvira et al. 2010) or by weak acids, and the pentose conversion enzymes are needed to use these substrates. Since the 1980s, several different enzyme systems have been developed for this purpose, although the ones from Novozyme in Denmark are the most used today. In addition, patents have also been approved in China and the US for other enzyme systems. This has made it possible to also use cellulosic material (He et al. 2011) as substrate, like wood (Schmer et al. 2008). Different substrates as well as thermofilic fermentation (Xu and Tschirner 2011) has come as a complement to mesofilic (Georgieva and Ahring 2007).

Most ethanol is produced in Brazil and the US, which both produce more than 4 million tons per year. In Brazil, ethanol is a way to utilize internal biomass resources such as sugar cane, and thereby avoid import of oil for vehicles. Actually, almost half of the vehicle fuel is ethanol there. In the US, ethanol is subsidized by giving a guaranteed price per litre. Most of the substrate is corn and wheat produced in the mid-west, where the farmers probably would be bankrupt without this possibility to a great extent, as there is otherwise a surplus of cereal production. At the same time this replaces imported oil, approximately 4–5% of all consumed annually. It is not very efficient from a green house perspective as coal is used for the processing of the ethanol, like distillation, while bagass is used for the same in Brazil, and biomass in Sweden.

Originally ethanol was produced in quite dilute liquor. During the development of the Brazilian ethanol program during the 1980s, the dry solid concentration was increased and almost "solid phase" fermentation was introduced. By this method, the amount of water that had to be evaporated was limited, and thus the energy demand also decreased. This technology has been further developed in several research groups, among others at Tsinghua University.

Different types of system solutions (Farrell et al. 2006) have been presented and sometimes also implemented with bioethanol as the base (Prasad et al. 2007). Pretreatment by steam explosion and combination with biogas production from residues is one example (Dererie et al. 2011). Simultaneous saccharification and fermentation is another example (Karimi et al. 2006). There are many discussions about the sustainability of ethanol production. Are we using food for energy demands, or is it just giving farmers the possibility to survive (like in the US Mid-West?). These types of discussions have strongly decreased interest for ethanol production in many countries. Farrell et al. (2006) gives positive momentum and arguments for the production.

8.1.5 Waste to Energy

There are huge amounts of organic waste from households, restaurants and agriculture. Much of this stems from a long term food storage issue. Thus, by having better storage this amount can principally be reduced. Still, we often get too much food when we go to restaurants, and what we cannot eat becomes organic waste. Sometimes this can be used as food for pigs, other animals, or just for rats. In many countries, the residues are used to produce biogas, when possible. However, a lot of the material cannot be degraded biologically, and therefore is combusted.

Thus, many countries have built plants for waste combustion, or incineration. There are recommendations that spent material should first be reused. If this is not possible—recycled, like plastic bottles and tin cans. The next step is to convert by fermentation and digestion to produce biogas. If this cannot be done, we can combust, and the last alternative on this "chain" is deposit material.

Waste to energy is primarily alternative 3 and 4 (Kothari et al. 2010). In an EU project around the Baltic Sea, region waste resources were identified and conversion methods evaluated in pilot plants for biorefinery and solid phase biogas production (Thorin et al. 2012). What we can see here is that the potential for efficient reuse of material for both chemicals production and energy use is significant.

8.1.6 Pyrolysis and Torrefaction. Biochar.

Pyrolysis is a milder form of gasification and combustion. The purpose is to thermally degrade wood materials into a liquid fraction that can be used as a replacement for oil, and a solid bio-char fraction (Di Blasi 2007). Different chemicals can be produced from this (Yaman 2003). The temperature is important (Hossain et al. 2011). If it is higher, less char is produced and vice versa. Torrefaction is an even milder heat treatment at ~250–280 °C, where the focus is on production of bio char that is more compact than "normal" biomass, and thus more energy efficient when transported long distances (van der Stelt et al. 2011). Different types of material can be used as substrate. Malkow worked with mixed solid waste (MSW) (Malkow 2004), and Tao et al. works with addition of catalysts to enhance the pyrolysis (Tao et al. 2015a, b).

8.1.7 Bio Refineries and Buthanol

A step further, compared to what has been described above, is to actually produce a number of different chemicals using microorganisms or high temperature gasification. These types of plants are called biorefineries, and Kamm and Kamm (2004) describe them in detail.

Many researchers have worked with microorganisms. Brennan and Owende (2010) investigated how microalgae could be used as substrate in a biorefinery. Cherubini et al. (2009), Cherubini (2010) and Cherubini and Ulgiati (2010) studied biorefineries from a holistic perspective and also performed LCA analysis of a system. Dalton and Stirling (1982) performed studies with mixed cultures and co-substrates quite early. This was later substantially studied by Kumar and Gayen (2011).

Butanol is a very important product, as it can be used to produce other chemicals. Napoli et al. (2010) studied production in a continuous packed bed reactor, Qureshi et al. (2010) used agricultural residues and Wang and Chen (2011) investigated fermentation of butanol by removal of inhibitors.

Sulphite pulp mills have integrated production of many different chemicals like vanilla, ethanol, lingo-sulphonates, dissolving pulp and lately nano-fibres. Examples of these are in Boregard in Sarpsborg, Norway (Kristiansen 2010), Rødsrud et al. (2012) and Modahl Saur and Vold (2010).

Bjørsvik and Minisci (1999) studied synthesis of vanillin, Boerjan et al. (2003) lignin biosynthesis to understand the mechanisms, Bogetvedt and Hillstrom (1996) how mills could be upgraded, Berntsson et al. (2006) how a future optimized bio-refinery mill might look, Atsumi et al. (2008) how further refinement could be made to produce higher alcohols for biofuels. Amidon et al. studied how different chemicals could be produced, and Andersson (2007) how an energy optimized mill could be achieved. Kleinert and Barth (2008) focused on hydrogen-enriched bio-fuels, while Loe and Høgmoen (2011) studied CO_2-friendly processing of wood to vanillin.

Lucia et al. (2006) and Luo et al. (2010) studied wood to chemicals from an environmental perspective, while Mosier et al. (2005), Tucker et al. (2003) and Mtui (2009) investigated the effect of pretreatment of lignocellulosic materials.

Another kind of process solution is to add thermal gasification to an existing pulp mill to produce different chemicals like H_2, CO, CH_4, but also integrate recovery of the cooking chemicals in the gasification process as described by Naqvi et al. (2012a, b, c). Here, removal of CO_2 from the gas stream for storage is also included (CCS).

Gressel and Zilberstein (2007) studied how biorefineries could be used in "developing countries".

8.1.8 Measurement of Energy Properties

Different kinds of biomass have different properties. The amount of lignin varies as well as hemicellulose and cellulose. Organic waste has even more complex components, such as different types of plastics, wool and other textiles.

Bassam el (1998) studied different types of energy plants and their use. Robbins et al. (2012) studied the impact of different biomaterials in relation to chemical conversion and Samuelsson et al. to CO_2 emissions. Tao et al. (2012) studied properties for different species. Kukkonen (2011) tested growth of fast growing grasses in a tropical environment reaching up to 100 ton DS/ha, y! Vassilev et al. investigated composition of different species. Walker (2006) gave a review of basic wood chemistry, which can be used to identify possibilities. At Brunnby outside Vasteras in Sweden (2006), different plant species were grown under controlled conditions and fed different types of nutrients, such as residues from biogas production, sludge from waste water treatment plants and synthetic fertilizers, in parallel to manure. Uptake of heavy metals as well as organic complex substances were followed and very little uptake was found over the last 15 years. Hemp was also tested a few years ago. Depending on the amount of nutrients, different subspecies type and water feeding, the production was 7–12 ton DS/ha,y. At another site close by 19 ton DS/ha, y was achieved. However, this was measured in October; when harvest was made in February of the next year the yield was much lower, approximately half. A lot had gone back into the soil.

AEBIOM (2014) is the biomass producer's organization in the EU27. They present statistics of biomass produced in different forms annually. Gaur and Reed (1998, 1995) gathered a lot of biomass thermal data into an atlas that can be useful in evaluating potentials for different type of biomass.

Dellomonaco et al. (2010) described how biomass processing could be done in a biochemical way.

Hakalehto et al. (2009) developed a tool to determine growth rate of microbes, while Nyström et al. (2003), Nyström and Dahquist (2004), Nystrom et al. (2005), Nystrom (2006) studied and developed technologies to determine moisture in different wood and other biomass species using radio frequency (RF) scan as well as near infra red (NIR) spectroscopy. Lestander and Rhén (2003) studied NIR spectra correlated to both moisture content and heating value, which is important especially for use in power plants.

Moisture content is essential when using the biomass in combustion or digestion at pulp mills, since temperature is affected and thereby the moisture content is important as input to the boiler control. Paz et al. (2008), Paz (2010) performed deeper studies around the RF method, and investigated the amount of ash in biomass, especially water soluble salts.

Moisture content is also important when storing biomass. High amounts lead to mould growth, and thus it is imperative to avoid air coming in contact with the biomass if possible. Passoth et al. (2009) has studied this.

8.1.9 Combustion and CHP

The most common use of biomass, other than as raw material in the pulp and paper industry, is as fuel in combustion processes. One special use is in combined heat and power plants, where steam is produced and then used first in a turbine cycle to produce electricity. Then it is condensed and the heat is taken out for district heating.

Biomass for cooking food is the most important use, since a majority of poor populations in developing countries have to rely on this for their survival. Often wood is picked for free in nature, creating a shortage around villages. This also gives very little incentive for replantations, as no one earns money on this type of crop.

Yan et al. (2013) studied how biomass can be utilized in combinations where heat and power is combined with production of chemicals and carbon capture and storage in pulp and paper industries as well as in biomass fired power plants. Naqvi et al. also studied similar concepts (Naqvi et al. 2016).

Heat can also be generated at the CHP plant and used to melt salts like erytritol with a melting point around 127 °C, or different parafines with varying melting points in the range from some 50–130 °C as discussed in Li et al. (2013) and Wang et al. (2010). Here, the smelted salt is then transported to local heat plants where the stored heat is taken out while the salt is solidified again. In this way, quite a high amount of heat at a specified temperature can be stored, transported and used. Other examples are given in Dahlquist (2013).

8.1.10 Energy Pathways and New Applications for Biomass

There are many possible pathways to convert biomass into useful product. Gasification at high temperature will give syngas with CO, H_2 and methane, which can be separated or directly used for conversion into other chemicals like bio-diesel, methanol, dimethyl ether etc. Pyrolysis occurs at lower temperature, which gives organic solutions that can be further refined into fractions similar to fossil oil. Torrefaction dries and partly burns wood to get a product that can be compacted, and thereby easier to transport long distances then what is economically possible for the much more voluminous pellets of “normal” biomass. Biorefineries and biogas production on the other hand are not thermal processes but microbial using microbes or yeast. Different pathways for how to go from a fossil fuel dependent to an independent society are discussed in Dahlquist et al. (2007), and in Yan et al. (2007) we look at how to move from today’s processes in the pulp and paper industry to more chemical production with gasification of black liquors.

Other routes are available to process pulp fibres further into nano-fibres, which can be used to form very flexible and strong surfaces or various moisture thickeners for paint and food (Klemm et al. (2011) and Siró and Plackett (2010). Also, lignin can be used for other products like tensides, medicine precursors and more as shown in Lebo et al. (2000).

8.2 Use of Energy

In Fig. 8.1 we see the total energy use per capita as a function of income per capita. In the first figure we have the values for 1975 and in the second for 2007, where we also see the development in Sweden from 1960 to 2007.

The development from 1975 to 2007 can be seen by comparing the data in Fig. 8.1 to those in Fig. 8.2. Here, we see that big countries like China (big red circle) and India (big blue circle) both have moved strongly up towards the right and top reflecting that both energy use per capita and income per capita have increased substantially. This trend is seen for most countries outside Africa South of the Sahara, and some exceptions like, e.g. North Korea and Haiti. Commonly, poor development has been in countries with weak (democratic) governmental structures.

In Figs. 8.3 and 8.4 we see the corresponding figures for electricity consumption per capita as a function of income per capita in 1975 and 2008, respectively.

What we can see here is that electricity consumption has increased a lot along with the income in big countries like China and India between 1975 and 2008; where we also can see that Chinas has developed faster than India with respect to both income per capita and electricity consumption.

It is noteworthy to look at how energy is used. In Fig. 8.5 we see distribution of energy use in homes with respect to major activities in the EU countries in 2005.

Break down of household energy for EU-countries 2005 from Bosseboeuf (2009).

Another interesting aspect is how much heat is needed as a function of out-door temperature. In Fig. 8.6 we see how the correlations for heat is a function of out-door temperature in central Stockholm for approximately 10 000 offices, shops and similar.

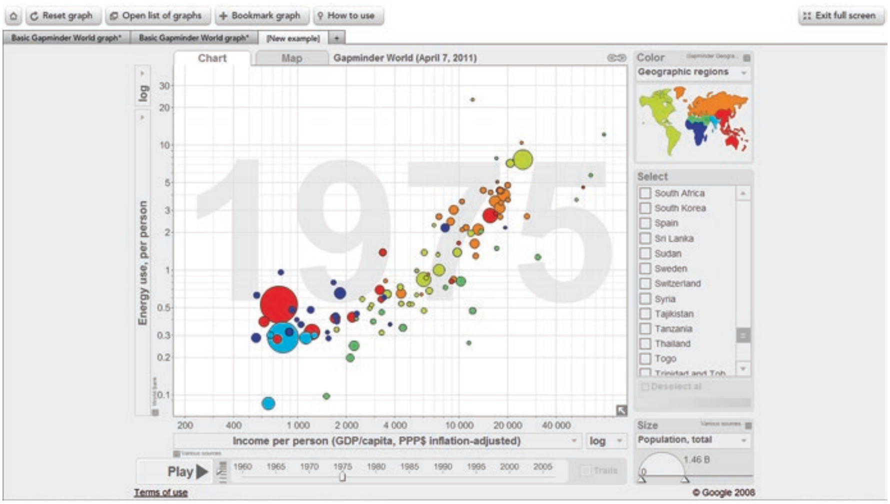

Fig. 8.1 Total energy per capita as a function of income per capita 1975 (From Gapminder/World bank data)

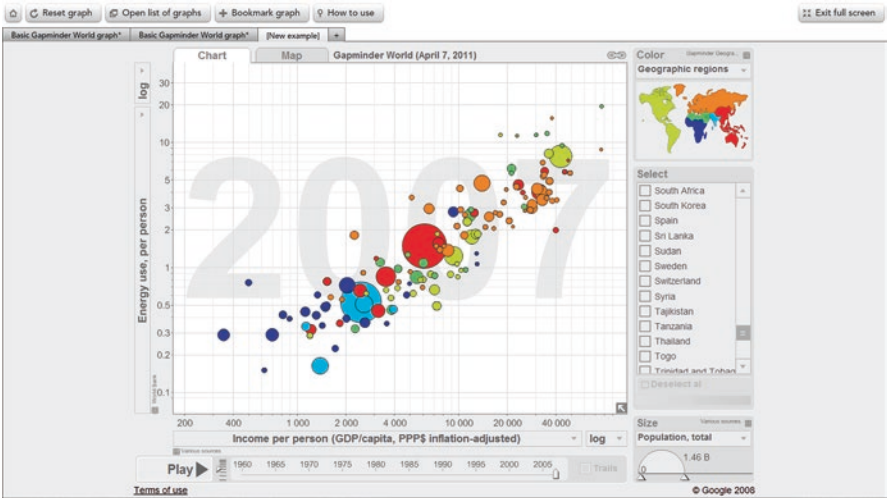

Fig. 8.2 Total energy per capita as a function of income per capita 2007 (From Gapminder/World bank data)

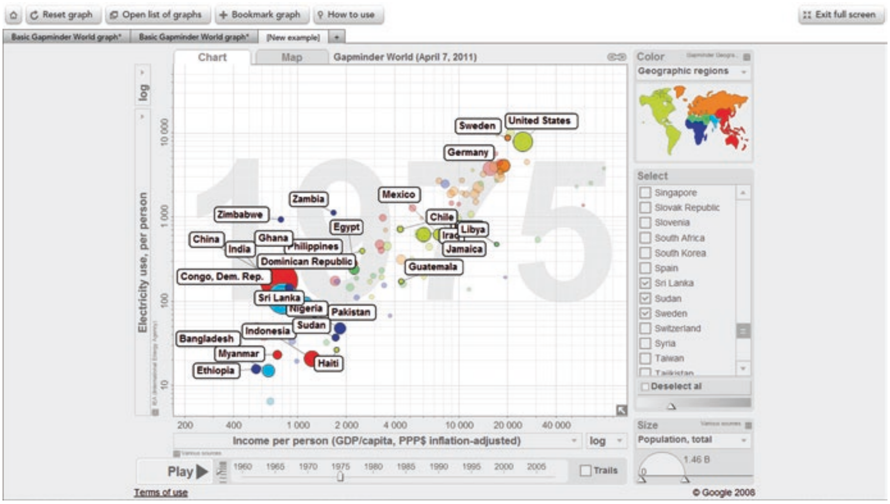

Fig. 8.3 Electricity consumption per capita as a function of income per capita 1975

We also see that the curve is steeper (red) during weekdays than at weekends. Logically it should have been the opposite, as during working days with many people and computers we have internal heat sources, but in reality we ventilate so strongly and have such poor heat recovery that we get this result as seen.

Renovation of old buildings can give significant energy savings. A typical value for heating buildings in Scandinavia is 200 kWh/m^2,y in buildings from before

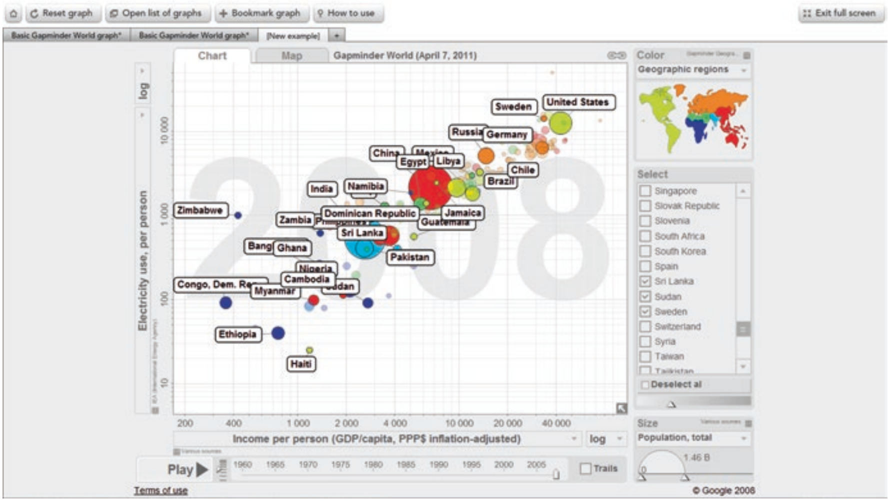

Fig. 8.4 Electricity consumption per capita as a function of income per capita 2008

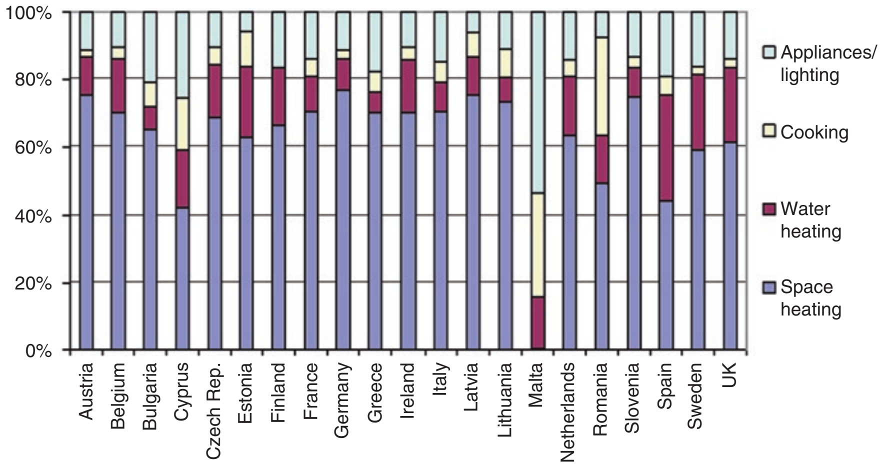

Fig. 8.5 Energy use distributed on different activities in EU-21 countries 2005

1980. For new buildings with good energy standard, but also when older houses are renovated, we can expect 50 kWh/m^2,y. Approximately 60% of the energy seen in Fig. 8.1 is for space heating. This means that the potential savings could be 60% *(1−(50/200) kWh/m^2,y) = 45% of the total household and building energy, if we extrapolate from the discussion about buildings in Scandinavia. For the EU using 3310 TWh/y, the potential savings then are 3310 * 0.45 = 1490 TWh/y.

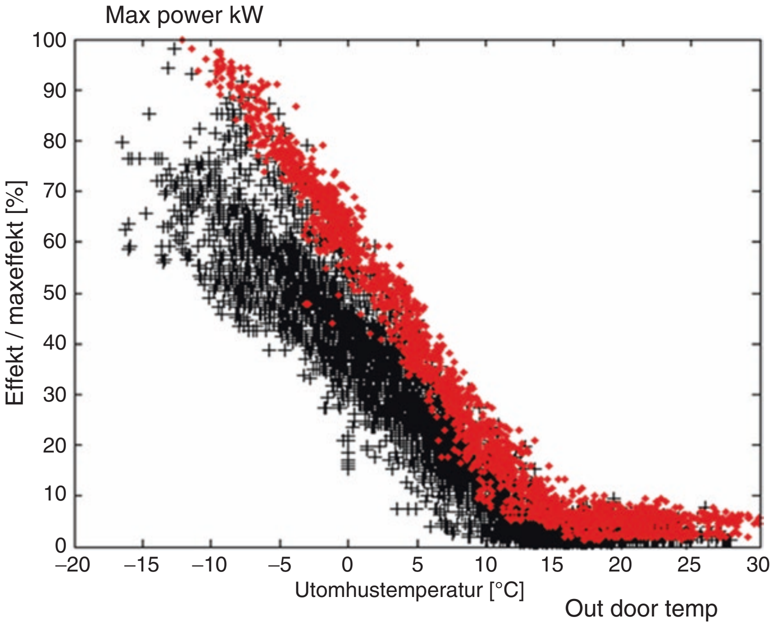

Fig. 8.6 Heat demand as a function of out-door temperature during week days (red) and weekends (black) in central Stockholm. This is for offices and shops

In many countries light is an important part of the electricity consumption. If we replace fluorescence lamps with LED-lamps the EU27 could save approximately 100–150 TWh/y. Lighting is approximately 10–15% of all energy use in households, and it is even higher in offices and services. Generally, LED lamps will consume 50% of the corresponding fluorescence lamp, and 10% of the wire lamp. According to regulatory demands wire lamps should not be used, at least not for stronger lamps, so some of this potential may have already been implemented, although the overall figures are lagging behind, and data cannot yet be retrieved.

There are also a number of other measures available to potentially save energy. One is to reduce the amount of food becoming waste. Investigations in the UK indicate some 30% waste, while some Swedish investigations indicate 10–20% (Karlsson-Kayama 2009). Some of the waste comes from bad weather conditions that cause poor crop harvests. In some countries rats and other animals eat and destroy a lot of food while being stored. Mould is another problem if the food is too moist. Better logistics and control of the storage will reduce the waste. It should then be possible to reduce the energy consumption by at least 10% (probably 20%). This would mean some 150–200 TWh/y for the EU27, as the energy in the food is approximately 1000–1300 TWh/y + 500–650 TWh/y for food production or 1500–1950 TWh/y all together (2016)!

8.3 Transportation with Personal Vehicles

We can expect only series plug-in-hybrids and electrical vehicles by 2030 (including fuel cells). This would reduce fuel/energy demand by 60–80%; as approximately 70% of personal travel is shorter than 50 km, we can assume 70% electric and 30% fossil fuel. Biomass can be converted to biogas, ethanol, bio-diesel or similar, and there is enough biomass to cover 100% of the fuel need! This means a reduction from approximately 2920 TWh/y to 820 TWh/y for transportations related to personal transport (−72%).

8.4 Transportation of Goods

Transportation of goods will be a bit more difficult to reduce this far, but the potential should be at least some 30–40%, if more transportation is done using rail transports. If we can solve the battery problem by developing technology with electric drives that can also be used for heavy vehicles, the reduction in energy need can be reduced to the same level as for personal vehicles. We then may also see trucks and buses with series hybrids on highways.

By replacing fossil fuels with biogas, DME, FAME, methanol or ethanol we can increase efficiency of combustion engines by higher pressures.

8.4.1 Industry Use

In Table 8.1 we see potentials for reduction of energy use in process industries. Reducing the demand for primary energy like live steam, fuels etc., and modifying processes to reduce the amount that is scrapped will lead to overall reduction. In this way, energy introduction to material that is scrapped later on is avoided, and thereby energy is saved.

From these different actions we can see that there is a significant potential for energy efficiency improvements in all industries, although not as much as for electrified vehicles or highly renovated buildings.

Table 8.1 Potential reduction of energy use in EU27 heavy industries

	TWh/y
Non Ferrous Metal	15
Ferrous metal	250
Cement industry	30
Pulp mills	30–50
Paper mills HC formation	28–45
Lime kilns	7
Total savings potential	310–340

8.5 Energy Balance for the EU27

We now look at the overall balance for the EU27 including the electricity production and energy demand vs potential for energy savings.

The available biomass resources are in the range of 8500–12 500 TWh/y for the EU27. Wind power today produces more than 100 TWh/y but with a potential for at least 1000 TWh/y. Solar power still is relatively marginal, but solar power has the potential to produce some 200 TWh/y within ~20 years, if we place PV-cells on half of the house roofs. Today, hydro power is 10.2% of the total 3400 TWh electricity produced, or 350 TWh/y. These TWhs are very important as they are principally the only energy that can be stored for electricity production alongside biomass in thermal power plants. Especially in the northern EU, hydro power balances wind and solar power in, e.g. Germany and Denmark. Nuclear power gives 29.5% or 1000 TWh/y of the total electric power, although the installed capacity is in the same range as wind and hydro power. Since it is used as base power, we get so much more energy out.

If we accept nuclear as a non-fossil resource the available resources would be (8500–12 500) bio + (100–1000) wind + (5–200) solar +350 hydro +1000 nuclear =9955–15 050 TWh/y.

The primary energy demand today is 16 000 TWh. It would be approximately 12 000 TWh/y with the potential reductions. If we replace nuclear with renewable, it is further reduced to 11 000 TWh/y, as the heat released from nuclear power plants is added to primary use according to how it is calculated in official figures.

This shows the possibility to balance the demand for energy with the non-fossil fuel produced electric power, heat and electricity for vehicles and transportation. To drive this forward now demands good incentives, such as a combination of new cost efficient technologies, tax on fossil fuels, green electricity certificates and subsidies to new technologies like the next generation of batteries etc.

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Chapter 9
Impact on Climate and Environment

Erik Dahlquist

9.1 Climate, Global Warming and CCS

If we go back 50–70 years, the great question was about food supply and the risk for nuclear war that would destroy all humans. The Nobel Prize laureate Svante Arrhenius, 120 years ago, worried about a new ice age, and recommended that we should burn all known fossil fuel resources, as the CO_2 would increase the temperature through the green house effect. During the 1960s the concern for green house effects started and since then has increased, but the emphasis has not been on too high a temperature increase that will negatively affect living conditions globally. Allen et al. (2009) and Andres et al. (1999) discuss the cumulative effect due to carbon dioxide emissions from burning fossil fuels during the last 100 years. In Searchinger et al. (2008) the effects on release of CO_2 from changed farming methods are discussed. Möllersten and Yan (2001) and Möllersten et al. (2003) discuss the possibility to remove CO_2 from exhaust gas from power plants using fossil fuels as well as the possibility to store the separated CO_2 underground. In Möllersten et al. (2004) the possibility to remove CO_2 through CCS in the pulp and paper industry is also discussed, although biomass is used there. This is because CO_2 streams can be higher in concentration, and thus more economic to remove.

Ernfors et al. (2008) also studied NOx emissions, which do not directly or primarily affect the atmosphere through green house effect, but increase growth of, e.g. algae in lakes and seas, affecting local climates. This is also something to consider, as it will significantly affect biodiversity.

The cement industry affects CO_2 emissions very strongly since new buildings are built using concrete. Figures about this are given in Cembureau (2010). The emissions come from heating $CaCO_3$, using mostly fossil fuels, and the calcination when $CaCO_3$ is converted to CaO at high temperatures (above 1000 °C).

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Springer International Publishing AG 2017
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The climatic and environmental development are covered in many different sources, two of particular interest are Earth Trends: Environmental Information (2010) and World Bank development indicators (2016).

9.2 Biologic Diversity

Although, biological diversity is not a focus point in this book, we will just emphasise that the number of species on earth today is in the range of several billions, while we only recognize approximately 1.7 million or thereabout (nwf 2016).

Plants have high values as food, but also half of all synthetic drugs actually have an origin from crops; 40% of the most sold in the US are among these. Many plants (50%) only grow in one country and 42% of all terrestrial vertebrates are also only found in local areas or regions (nwf 2016).

Definitions about biodiversity and more discussions around this are found in, e.g. Greenfacts (2016). There are predictions that around 20% of the species known are on their way to extinction and some researchers say that we are right in the middle of the fifth or sixth major extinction seen historically since earth became populated by living species billions of years ago. The speed of species extinction is very high right now, mostly due to the new farming and living methods used over the last 50 years.

9.3 Environmental Issues and Waste Water Treatment

The major environmental concern today is the global warming issue; 30 years ago it was primarily sulphur emissions and 20 years ago mostly nitrous gases. Water concerns have focused on phosphorus and nitrous compounds, which both give eutrophication. Thus, the main demands on waste water treatment plants are on limitation of these two elements.

Phosphorus is normally removed by precipitation with iron or alumina salts, while nitrous compounds normally come as proteins and ammonium type of compounds. These are normally first oxidized and then nitrate is reduced in a second process to elemental N_2.

The metal phosphate precipitate usually also contains other metals, and thus to avoid polluting the soil it is not normally recycled to farmland. The phosphate is also strongly bound, and thus difficult to get back to crops. The problem with removal of phosphorus from the natural cycle has been studied by Vaccari (2009), who points out that a deficiency of phosphorus for fertilization may be a fact soon; especially clean phosphorus without cadmium pollutant in it, like the one often taken up in Northern and Western Africa.

Nitrogen removal is a very energy intensive process consuming a lot of electricity for aeration. The aeration electricity consumption can be reduced to half using the anammox method. With a combination of algae (which produce oxygen) and microorganisms (which decompose organic matter), we can achieve lowered electricity consumption and at the same time build phosphate or nitrous compounds directly into algae. This has been studied at several places, such as Malardalen University and the waste water treatment plant in Vasteras, Sweden (Thorin et al. 2014).

Another important issue is spreading sludge on farmland if there are other types of toxins. Heavy metals are one thing, especially cadmium, nickel and similar, but lately also medicines, non-ionic tensides and micro plastics have been noticed as possible threats to humans, if some is taken up by crops. Odlare et al. (2011) studied uptake of metals and organics in crops at a test center outside Vasteras over 15 years, where waste water treatment sludge as well as residues from biogas production from household waste has been studied with respect to uptake into cereals. So far, no alarming levels have been seen.

Hydrocarbon emissions from firing wood in inefficient stoves or open fire is a strongly unhealthy atmosphere for humans, and have been studied by a number of researchers like Ludwig et al. (2003) and Melillo et al. (2009).

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Chapter 10
Policies and Incentives – Natural Resources Available Today and in the Future: How to Perform Change Management for Achieving a Sustainable World

Peter Stigson and Erik Dahlquist

10.1 Economic Incentives and Controls Like Taxes, Subsidies, Feed-in-Tarifs, Tolls

In Germany, Spain and Denmark, renewable energy technologies like wind and solar power have been promoted by feed-in tariffs. This means that the supplier is guaranteed a fixed price for every kWh electricity delivered to the grid. In Germany, this is approximately 0.4–0.45 €/kWh for PV-electricity, 0.1–0.15 €/kWh for wind power and approximately in the same order of magnitude for thermal power from biomass. The price is guaranteed for some 25 years. This has given very strong expansion of both wind and solar power, and installed capacity in Germany is 35 000 MW solar power and approximately 40 000 MW wind power as of 2016. In Spain, there was also a significant expansion in the same way, but the incentives were taken away and thereafter the installations went down.

In other countries like Sweden, Norway, India and Italy, green electricity certificates were implemented. This means that all consumers pay a certain fee per kWh they buy. This amount then must be used for building new power capacity with renewables, such as PV, wind and biomass, but also some hydro and wave power. This has had a strong effect in Scandinavia for expansion of biomass fired thermal power, especially in Sweden, where biomass is richly available, but a lot of wind power has also been built. Today, Sweden has more wind power installed than neighbouring Denmark, which is known as the most wind power friendly country in the world with almost 50% of all electric power coming from wind. In India, it is mostly wind power that has been installed, but also PV-cells.

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Springer International Publishing AG 2017
E. Dahlquist, S. Hellstrand (eds.), *Natural Resources Available Today and in the Future*, DOI 10.1007/978-3-319-54263-8_10

The strong incentives in Germany led to both high installed capacity of PV-cells, but also to a strong reduction of price for especially crystalline PV cells. The price is now approximately 1/3 of what it was per m^2 just some years ago, and the efficiency has more or less doubled.

This shows what effect strong incentives can give. A problem has been that German PV-cell manufacturers are not able to compete with Chinese companies, supported strongly by the Chinese government. This is a complication due to that different countries give different conditions to their industries. Long term this is still good, as reduced price gives increased installation, which is positive from all means. That living conditions increase in China due to increased production also is good, and salaries are thereby increasing, neutralising the salary effect long term. Better processes and process control is winning long term.

There has been a strong global focus on dealing with emissions of CO_2 and other greenhouse gases. From an historical perspective it is interesting to note that when scientists found out that freons caused depletion of ozone in the atmosphere, it was relatively easy to ban at least "hard freons". The only supplier was Dupont, and they could switch to "soft freons" with hydrogen alongside of halogens and carbon. For CO_2 the problem is much worse as many countries have large reserves of fossil fuels, such as coal, natural gas and oil. It is much easier to tell someone else to stop producing or using something negative than to do it yourself. Therefore, the opposition towards stopping the use of coal is very strong in coal rich regions in the US, China, South Africa and Germany, at the same time as central organisations in several of these countries really see the need to reduce burning coal. In China, the first objective is to reduce the strong negative effect on people's health due to the emissions of not cleaned gas from the combustion. In the US, states with no coal but resources of other kinds are much less interested in sustaining production and excavation of coal ores than those with coal. Thus, fracking has become interesting as many areas can make money out of this new technology, at least short term. This is good from the federal perspective since the US would not need to import so much oil from Arabic countries like Saudi Arabia.

Regulatory systems may differ quite a lot between countries. Oil production in Norway is made in such a way that the Norwegian government takes the cost for prospecting new fields. Oil companies then bid for production, and the one giving the best condition to the government gets the project. The government then invests the earnings in primarily buying shares in strong companies all over the world and new prospecting. A certain percentage of the annual increase in the value of the shares is used in the "normal" budget, to avoid problems for other Norwegian industries. Also, this avoids problems for the overall economy that many oil countries face when the oil price is low.

In all countries, we also have regulations that state what emissions are acceptable with respect to different substances. For instance, there are principally the same rules all over the EU for phosphorus and nitrogen.

Concerning control of chemicals, especially some of the big companies have policies to avoid use of hazardous chemicals and materials. Life cycle assessment (LCA) is performed for different technical solutions during product development to find the best solution. If the cost is not prohibitive, this best solution is selected and used. Here, benefits from many different areas are combined to give the overall motivation as well.

10.2 Policies and Governance of Natural Resources

10.2.1 Introduction

Natural resources as well as our emission budgets to meet established sustainability goals and resilient societies are becoming limited. Improved policies and governance[1] — in public and private spheres — is needed to establish more efficient and effective agendas for change towards reduced resource and emission intensities. We are inherently and rapidly moving towards a resource and emission constrained world; a world that will consequently demand resource efficient and low emission solutions. Several nations have realised this and adopted policies to take a lead in this transition, seeing such solutions as fundamental to their economic development.

However, this overall understanding and subsequent policies are not necessarily easily transferred to policies and governance in the fields of natural resources and sustainability, such as governance of natural resources, climate mitigation and adaptation, sustainable energy systems and other environmental, social and economic goals. Focusing on natural resources and climate, both are surrounded by highly complex system interactions, where an action to achieve one objective causes a number of positive and negative systems effects. As an example, an energy system is only sustainable if it is water and land-use smart, and vice versa. Despite this, silo approaches focusing on single objectives and sectors are predominately used in natural resource and climate analyses as well as subsequent policymaking and business decision-making. This neglects how actions within one policy area or sector, affects other sectors. As a result, what is regarded as sustainable may very well not be sustainable from a broader systems perspective.

Systems approaches must therefore be applied both in selection of policy instruments and policy processes (i.e. policies), design of policies, management of policies, and policy evaluation. This chapter will discuss the need for better resource governance, valuation of natural resources as well as policies in terms of policy processes and instruments. The objective is to inform policy and decision-makers about important concepts and conditions for improved resource governance and policies that can bridge system complexities and enforce, as well as incentivise synergistic actions within a broader set of policy objectives.

[1] Policies here defined as policy processes, goals and instruments in the public sphere. Governance is broadly defined as decision-making interactions and processes among a more diverse set of stakeholders.

10.2.2 The Need for Resource Efficient Governance of Natural Resources

The global resource systems — including natural and unprocessed resources, refined resources, products and wastes — are becoming increasingly complex and interlinked. Importantly, competition over natural (i.e. ecosystem) resources has grown tremendously, which emphasises the importance of more sustainable and resilient governance of resources. Factors highlighting the need to address the supply and demand of natural resources include global mega-trends that increasingly influence society and nature. Such trends include that the global population is expected to grow by one-third over the next 40 years, mainly occurring in Asia and Africa (UNDP 2015). As a result, about 85% of the global population will by 2050 live in countries which we today refer to as developing economies (ibid) and some 70% of the global population will live in urban areas (UN 2012). As a consequence of these trends, projections to 2030 point to a 40% increase in energy demand (IEA 2011) and a 70% increase in food demand (FAO 2011). These both contribute to a 50% increase in water demand (Leflaive 2012). Due to these trends and climate change, such as changed precipitation patterns, by 2030 two-thirds of the global population will reside in areas with high water stress (UNESCO 2012; Fig. 10.1). Additionally,

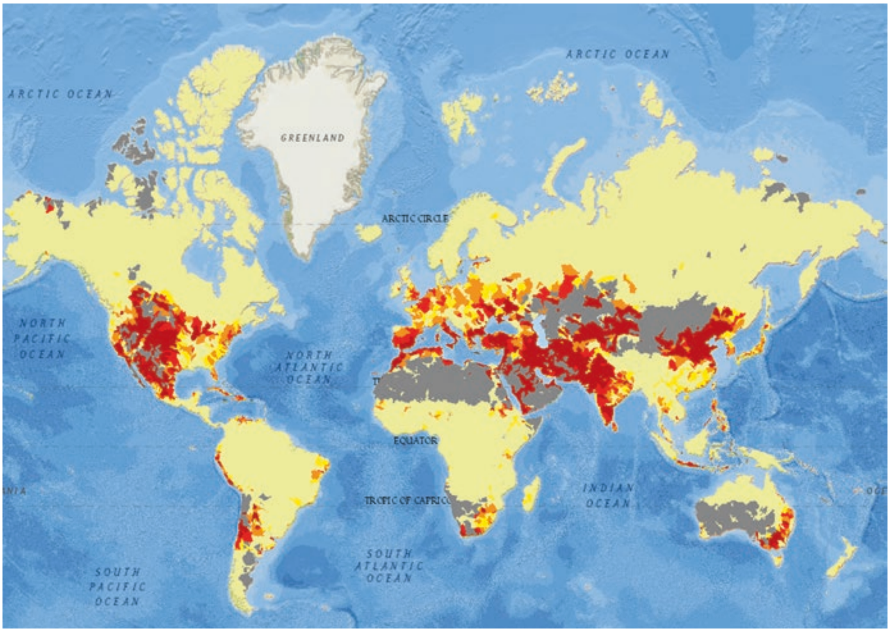

Fig. 10.1 Projected water stress in 2030 (Note: Projections represent a business as usual scenario. *Dark red* = extremely high water stress, *Red* = high water stress, *Orange* = medium-high water stress, *Dark yellow* = low-medium water stress, *Yellow* = low water stress, *Grey* = arid regions or low water use (WRI 2016))

1300 million people live in energy poverty, lacking access to reliable and affordable energy (IEA 2011). Furthermore, undernourishment is a reality for 850 million people (FAO 2012).

The focus for many countries during the coming decades will therefore be to increase social standards in terms of poverty alleviation, access to energy, as well as water and food security potentially overriding international climate objectives or other Sustainable Development Goals (SDGs). Emphasising the growth in developing countries, nearly 90% of growth in energy demand and two-thirds of investments in energy supply infrastructure up to 2035 is expected to occur in non-OECD countries (IEA 2011) and while water demand is expected to decrease in OECD countries, large increase in demand in other countries is expected to result in the aforementioned growth in demand (OECD 2012).

Unfortunately, the current rates of global ecosystem exploitation exceed the Earth's carrying capacity, with potentially large risks for humanity (Rockström et al. 2009). This provides a poor starting point for the above trends, as the effect is that many ecosystems are being, and have already been, degraded (Millennium Ecosystem Analysis 2005). Scenarios that predict a stable supply of natural goods and services, such as biofuels and water should consequently be challenged. We must supply the resources needed to build and maintain our societies with higher resource and ecosystem efficiency. It should also be emphasised that concerns about the availability of water, energy and land is not an issue limited to developing countries. Limitations to the development of water access, renewable energy, land-use, etc., due to interlinkages between systems and effects of climate change are found all over the world. As one example, the electricity production in the European Union is responsible for 44% of the freshwater extraction, while in some regions this exceeds 50% (European Environment Agency 2009).

10.2.3 Resource Systems Complexity as a Challenge in Governance and Policymaking

Research however indicates that the resources needed for an equitable and sustainable global development can be supplied sustainably, the concerns rather being limited understanding and lack of appropriate governance of ecosystem capacity (Hoff 2011). As a key concept for this understanding and governance, nexus approaches are highlighted as a methodology to evaluate and acknowledge the inherent interconnectedness between systems (Fig. 10.2).

Nexus approaches allow system interactions to be evaluated from different perspectives, of which two serve as broad classifications: *one* is the interactions between key resources for societies, namely between water, energy and land use; the *other* is the interactions between ecological, technical, and social systems. Such nexus approaches are parallel to an ecosystem based resource efficiency, taking a more fundamental system perspective compared to the more traditional view on resource and product based ecosystem efficiency, such as input-output analyses.

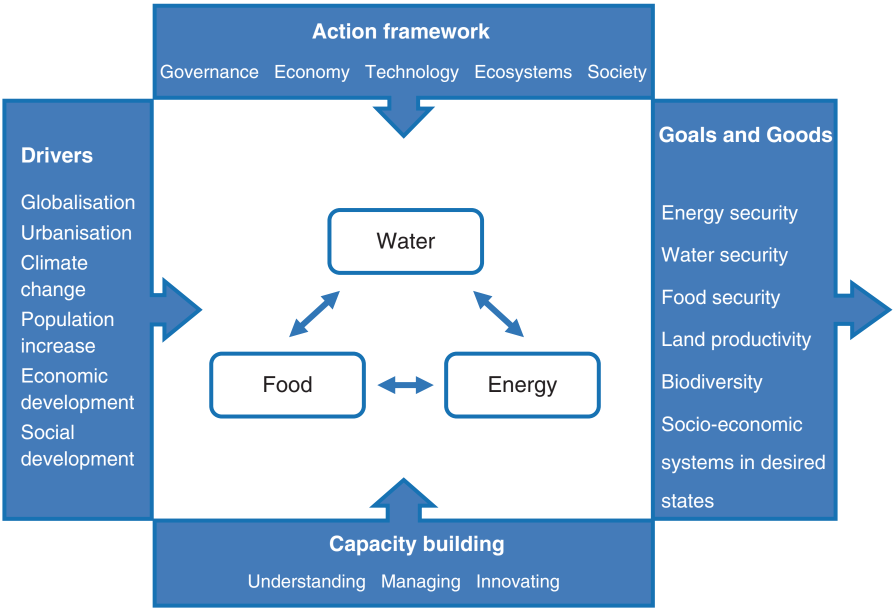

Fig. 10.2 Nexus approach (Source: Stigson et al. 2015)

A nexus approach provides a method to analyse uncertainties, risks, resilience, synergies and trade-offs in and between different systems to evaluate strategies that supply sustainability across scales and under the threat of climate change.

Different perspectives on what should be included in such analyses have been offered (e.g. Bazilian et al. 2011; EC 2012; Hightower and Pierce 2008; Hoff 2011; Howells et al. 2013; Stigson et al. 2015). As an example, interlinkages are emphasised by climate change, where resource efficiency holds many mitigation and adaptation solutions (Barret and Scott 2012), and given the impact of climate change on ecosystem capacities (IPCC 2014), the links between these two major determinants for sustainable solutions must be acknowledged. Hence, it has been argued that climate (i.e. an unchanged climate) should be part of the inner structure. In addition, it could be argued that limited resources, such as rare earth metals, should be included. Nonetheless, what literature as well as many businesses (cf. KPMG 2012; WBCSD 2014) agree on is that the systems are interconnected and that these linkages need to be analysed to identify trade-offs and goal conflicts (barriers) as well as synergies (opportunities). All linkages may not be important in all cases, however, as the spatial contexts pose an essential system perspective in a nexus approach, e.g. differences in blue and green water availability and demand.

Research on nexus approaches argues that present governance structures do not match the interlinked systems understanding and governing that a nexus approach necessitates (e.g. Nilsson and Persson 2012; Scott et al. 2011). The problem partly lies in the mandate to govern such systems approaches, as few organisations in few countries or regions have been given, or taken, the role to deal with these cross-cutting issues (Scott et al. 2011). From a policy and governance perspective, energy, water and land-use (incl. food, agriculture, forestry, flora and fauna etc.) as well as responses to environmental and social problems are commonly dealt with in isolated ministries and agencies, or academic journals and conferences. Moreover, businesses often have an isolated focus on the specific resources required for their operations.

This raises the question of whether we can meet the many political and societal goals and expectations that exist. Seeing the trade-offs and synergies as an integrated systems model means that global development must strive to avoid trade-offs and seek opportunities to reap benefits in system improvements. Due to the complexity, this typically lies in finding second-best opportunities (i.e. compromises between solutions) that provide integrated system improvements across wider scales rather than single, isolated gains at a cost to the wider solution. These scales include spatial, from the global to the local, systemic, including ecological, technical, economic and social systems, as well as chronological and organisational.

Hence, the key objective of nexus approaches is to facilitate a methodology to analyse and incorporate the competition of potentially scarce ecosystem resources into public and private decision-making processes. As one "super model" is unlikely to be able to incorporate all considerations, an appropriate methodology must be able to embed existing single system models and newly developed indicators and policy choice criteria into a comprehensive decision-making system, conjunctly with analyses of necessary solutions to governance challenges, as to provide an appropriate decision-making support system. This includes quantitative tools, and qualitative evaluations and guidelines, forming a basis for comprehensive analyses and understanding.

While systems analyses, as the opposite to silo approaches in decision and policymaking, are important to evaluate synergies and trade-offs, no one should expect win-win opportunities in a similar expanded systems perspective. While the number of winners and their gains may be optimised, losers will likely occur through prioritisation in the allocation of sustainable output from ecosystems. Here, systems analyses provides an additional benefit, namely as a basis for policy deliberations, providing arguments in the policy dialogue with different stakeholders.

A key point is, however, that while global mega trends may be possible to meet sustainability, such a development will not happen by chance, rather requiring informed decision-making that acknowledges resource competition between different systems.

10.2.4 Valuing Natural Resources

As such, there is a general understanding that the availability of natural resources is increasingly constrained. There are also several institutions that argue present economic models fail to accurately account for the value of nature.[2] This has spurred an

[2] For example, http://www.wavespartnership.org/.

interest in developing methods, guidelines and data to support the valuation of nature. This has taken several directions, such as valuing ecosystemservices and environmental-economic accounting (SEEA).[3] As an overarching concept, natural capital accounting (NCA) can provide a governance tool through deepened understanding of a nation's, region's or organisation's dependence on natural capital.

What Is Natural Capital Accounting?
Natural capital is generally considered to comprise three principal categories: natural resource stocks, land and ecosystems. All are considered essential to the long-term sustainability of development for their provision of "functions" to the economy, as well as to mankind outside the economy and other living beings (UN et al. 2003). In NCA, the definition of "accounting" means ways that business and nations can "take natural capital into account" in their decision-making. This could range from simple use of indicators through to undertaking a full account of environmental profit and loss in monetary terms through various approaches and tools. The NCA approach is applicable at a corporate, project, product or supply chain level (EC 2015).

This can be accomplished in different ways. From a societal perspective, it can inform about present and future — in the event of new policies establishing a price on currently unpriced natural resources — capital costs and gains for society in valuing different pathways for resource use and management. Examples include evaluating the value of different nutrient preservation measures in agriculture, setting a price tag on the societal value of such measures, and thus informing policymakers as well as the agricultural sector. From an organisational, or business, perspective, NCA can inform private governance of natural resources through valuing how the operations affect natural values, and hence the operations economic dependence on nature as well as potential economic risks of present or future policies targeting such natural services.

10.2.5 Policy Processes and Instruments

The increased resource demands were summarised as the world facing, or already experiencing, a resource revolution (Dobbs et al. 2011). An argument that could support the latter is that the price of several resources, such as food, fuel and metals, has started to undergo large fluctuations and experience a sharp price increase (de Groot et al. 2012). This means that actions to promote resource efficiency make sense from a sustainability and risk management perspective to lessen impacts on our social and economic development and to increase resilience in decisions and systems.

[3] http://unstats.un.org/unsd/envaccounting/seea.asp.

Hence, the benefits of resource efficiency are shared by a large group of stakeholders. The same stakeholders also hold much of the knowledge required to perform broad systems analyses and in policy learning processes (Scott et al. 2011; Stigson et al. 2009). This means an increased complexity in policymaking processes as well as private governance. However, due to globalisation and more interdependent resource, production and social systems, such intricateness is an inherent result of our development.

From a policymaking perspective, this promotes policy learning, where policy subjects take a role as policy analysts and advisors, informing policymakers on certain issues. This means that policymakers learn from exogenous knowledge in the policy environment — past experiences and expectations of the future — and use this knowledge to improve policymaking capacities. As such, it includes strong elements of a bottom-up approach. Thus, governments move from single policy decision-makers to act more as policymaking facilitators (Geurts and Joldersma 2001). The value of such policymaking approaches has strong support in literature (cf. van Ast and Boost 2003; Driessen et al. 2001; Etheredge and Short 1983; Geurts and Joldersma 2001).

The importance of capacity-building in complex policy environments is recognised by many and was emphasised in relation to climate change (being similarly complex in causes and effects as resource systems) as well as other complex policy environments (cf. Swanson and Bhadwal 2008; Papadopoulos and Warin 2007; Geller et al. 2006). Thus, complex policy environments require policy processes that build on stakeholder dialogue to achieve adaptiveness that can deal with both anticipated and unanticipated events in the policy environment in order for policy instruments to be effective. As such, a well-functioning dialogue among producers, sellers and buyers of resources as well as those governing these systems is important to identify the development of known and unknown events.

A value herein is that stakeholders are more likely to perceive a policy decision less negatively if they had the opportunity to voice their concerns and receive informed messages on why their demands cannot be heeded (Stigson 2010). This has policy relevance, as policy acceptance is a determinant for policy efficiency (Lucas et al. 2008).

This complexity in the policy environment has clear consequences for the choice and design of policy instruments. While a common perception in the design of a policy framework is "one goal, one policy", i.e. what is often referred to as the Tinbergen Rule (Tinbergen 1952), this is difficult to argue in terms of policy instrument design for resource efficiency. This is because it is understood that goals and policies will affect other goals and policies and there is a need for policy instruments that serve both general purposes as well as more contextual situations. In other words, we need to move from single stakeholder evaluations, to value chains and value nets, in order to find the most resource efficient solutions.

An example of policymaking under complexity is the use of emissions trading in the EU, which serves a general climate policy goal of setting a price on carbon dioxide emissions and through being a market based instrument, to a large extent allowing that market to settle on emission mitigation investments. However, emissions trading typically favour commercial or near market technologies and fails to support the RDD&D of CCS (Groenenberg and de Coninck 2008). Therefore, additional policy instruments are needed to support the development of CCS as potentially promising mitigation solutions. One such technology is carbon capture and storage (CCS), where most specific technology options are currently in a pilot and demonstration phase (GCCSI 2015). However, CCS is a chain of technologies forming a technology infrastructure from capture to transport and storage. Hence, specific policy instruments are needed in each stage of the infrastructure and no "one CCS policy instrument".

Similar situations of interdependencies are abundant in resource systems, as is argued in this chapter. As such, while general policy instruments, such as internalising externalities in the extraction of natural resources and increased costs for landfills in favour of recycling and reuse, serve an important purpose in dealing with complex resource systems, the policy framework and individual instruments must acknowledge interdependencies and spatial contexts. These spatial contexts have large variations depending on available natural resources and demand thereof. This argues that one policy per goal is difficult. Increased complexity in the use of policy instruments is an inevitable consequence of system interlinkages.

However, some policy instruments are more or less geared towards dealing with this situation. As identified by Ramesohl and Kristof (2002) and Krarup and Ramesohl (2002), negotiated agreements (NAs) have the potential to deal with complex policy situations while also stimulating dialogue and policy learning. Among more general policy instruments, in addition to taxes on virgin materials and landfill taxes, bonus malus systems and green tax shifts can be mentioned among those that provide broader support for increased recycling and reuse included in circular economy and sharing economy theories.

10.2.6 Conclusions

The governance of resources is a complex system with numerous system interlinkages. These interlinkages create synergies and trade-offs both from natural science and social science perspectives. Decisions by policymakers and businesses need to acknowledge this situation to increase the social effectiveness and efficiency of applied policies and strategies. Only then, can policies, policy instruments and businesses contribute to a sustainable and resilient development. Different methods exist to evaluate these system interactions. While nature can sustain a developing world, sustainable strategies will not happen by chance, meaning that we need to move beyond silo approaches and accept policy complexity as an inherent effect of plurality in the global resource systems. The choice of governance processes as well as instruments should acknowledge this and stimulate learning in how contextually appropriate solutions can be designed.

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Chapter 11
Is Circular Economy a Magic Bullet?

Malou Berndtsson, Lars Drake, and Stefan Hellstrand

11.1 Introduction

Humanity faces challenges in many areas in our efforts to achieve sustainability. There are biological and technical challenges but also social and economical challenges. How can our socioeconomic systems develop to better manage resources in order to serve humanity and preserve ecosystems for a very long time? Our inability to cooperate in solving our common threats and mismanagement may be the most difficult challenge. In this chapter we examine the *pros* and *cons* of circular economy. CE includes several good ideas and intentions; the challenge is to make it work in a complex market economy with a large number of individual decision makers with differing interests.

The problems we face concerning the environment and increasing resource scarcity have, to a large extent, grounds in the prevailing linear economic system (Jackson et al. 2014; Wijkman and Rockström 2012; EMAF 2012). Already in early reports, such as 'Silent spring' (Carson 1962), The economics of the 'Coming Spaceship Earth' (Boulding 1966) and 'The Limits to Growth' (Meadows et al. 1972) the consumption and production system was criticized for having a tendency to waste natural resources, to accumulate and spread waste and to assume existence of abundant natural resources. The current economic system can be described as a linear system following the logic of "take, make, waste" in regard

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Springer International Publishing AG 2017
E. Dahlquist, S. Hellstrand (eds.), *Natural Resources Available Today and in the Future*, DOI 10.1007/978-3-319-54263-8_11

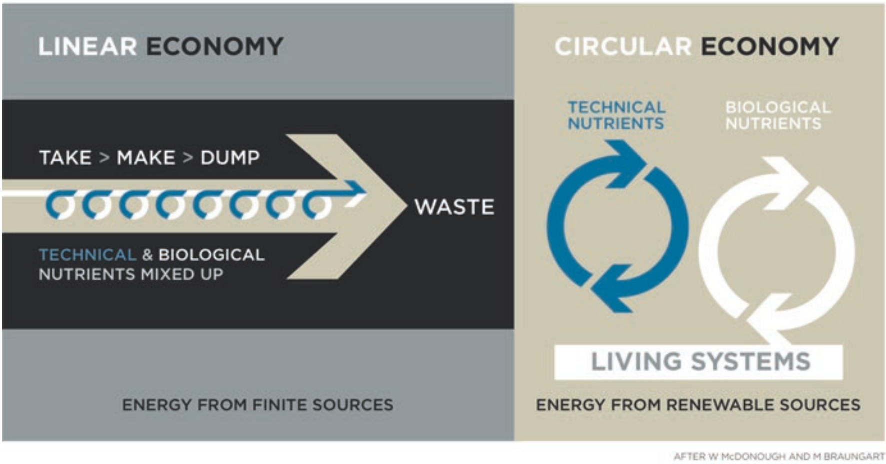

Fig. 11.1 Overview of circular economy (http://www.ellenmacarthurfoundation.org/circular-economy/circular-economy/rethinking-the-economy)

to natural resources. There is an obvious need for rethinking how our systems ought to work.

The fundamental idea in CE is to reduce resource use and waste of natural capital by building on the idea of nature's waste free cycles which are fuelled by solar energy. Circular economy (CE) has been suggested as a sustainable alternative for continued human and environmental welfare.

> The circular economy model uses the functioning of ecosystems as an example for industrial processes, emphasizing a shift towards ecologically sound products and renewable energy (Kopnina and Blewitt 2015, p. 21).

In this chapter we describe what proponents suggest and try to analyse what is new and its relation to sustainability. There is also a critical examination of the possibility to implement the ideas of CE.

Figure 11.1 illustrates the difference between a linear and circular economy.

11.2 The Concept of and Growing Interest in Circular Economy

In the 1960s and 1970s researchers such as Kenneth Boulding and Walter Stahel started arguing for the need of connecting the economy to the cyclical ecological system and the need to create an economy based on a loop system, a self-replenishing economy. However, it was two environmental economists, Pearce and Turner, who were the first to coin the term 'circular economy' in their writings of "Economics of natural resources and the environment" in the early 1990s (Li 2010).

Stahel's ideas on an economy based on a loop system were later picked up by the chemist Braungart and the architect McDonough that successfully launched the concept of cradle to cradle (C2C) in 2002 (Braungart and McDonough 2008). Stahel then further coined the term performance economy, distinguishing "between producing performance, selling performance (instead of goods) and maintaining performance over time (the circular economy)" (Stahel, 2015-05-17, personal communication).

As used today, the concept circular economy is a synthesis of the above mentioned and several underlying ideas that are put together within the framework of CE. It includes for instance concepts like cradle-to-cradle, performance/sharing economy, biomimicry and insights from industrial ecology (EMAF 2013, 2015). Like many other innovative solutions CE is in fact not new but rather reintroduced and reframed. For a strategy to be lucrative and gain popularity, old ideas are presented in a new way as a progressive intervention (Kopnina and Blewitt 2015).

Research and development work within CE is at present mainly driven by more or less business oriented organizations. The most known organization is The Ellen MacArthur Foundation (EMAF) which was formed in 2010. World record sailor Ellen MacArthur's analogy of the limited resources on a small sail boat and the limits we have on earth mirrors Bouldings (1966) rhetoric's of spaceship earth. EMAF re-actualizes old theories in a new concept and has successfully taken on the task to gather scientists and industry to spread the message of resource constraints and possible solutions found within CE. "*EMAF believes that the CE provides a coherent framework for systems level re-design and an opportunity to harness innovation and creativity to enable a positive, restorative economy.*" (EMAF 2015). The Ellen MacArthur Foundation is supported by a group of "Global Partners", big international corporations. The Ellen MacArthur Foundation and their work with CE is also supported by the World Economic Forum.

There has long been a perceived antithesis between financially and environmentally sound decisions. Circular economy has a strength in showing how these different goals within a business can complement and even reinforce each other in a world with scarce resources. When availability of many non-renewables (including metals, minerals and fossil fuel) cannot keep up with the rampant consumption demand and the regenerative capacity of renewables (such as land, forests and water) becomes strained to its limits — continued dependency on scarce natural resources exposes a company to serious risks (Rydén, 2015-02-03, personal communication). Thus, taking control over the resource flows back into the business is favourable for both environmental footprints and financial control.

The EU has recently launched a "Circular economy package". One reason why EU politicians jumped on the CE train relatively quickly in comparison to other suggested sustainability solutions could be because the economic case was perceived positive from the beginning. Some early calculations indicate economic growth and employment as a consequence of the growing circular business sector (EMAF –; Wijkman and Skånberg 2015).

> This is the future for business. ... The circular economy will not only enable businesses to tap into new sources of value, but help forge resilient markets and supply chains capable of delivering long-term sustainable prosperity. … The World Economic Forum, Ellen MacArthur Foundation and McKinsey suggest this circular transition represents a $1tn opportunity for the global economy. As such, it presents a significant opportunity for businesses and consumers alike to move away from our traditional linear 'take, make, and waste' economy towards a circular model. (Perella 2015)

The basic ideas of CE have been around since the 1970s and have been part of many discussions since that time. However, it seems to have been too early for the ideas to become generally accepted. It takes time for all revolutionary ideas to mature and for society to be ready for them. Webster thinks that now might be the time that society is ready for the circular economy. There are at least three reasons that may speak in favour of a breakthrough. The first reason is the resource scarcity, the second is that information technology is advanced enough to keep track of material flows in different places of the loop and third, there is a shift in consumer awareness and behaviour making us more willing to prioritize access to a product or service rather than ownership of a specific item. Ken Webster (in EMAF 2013, p. 15)

11.3 The Main Components of Circular Economy

> A circular economy has an aim to regenerate the capital, no matter if it is financial, man-made, human, social or physical and have production and transport systems that run on renewable energy. (Cradlenet 2015-04-01, our translation)

CE proponents claim CE to be a new paradigm for industry since it aims at regenerating ecological, social and economic value resulting in effectiveness that improves the state of the environment and even goes beyond sustainability (Kopina and Blewittt 2015, p. 238).

Each product produced in a circular economy should be designed so that the biological and technical components (types of material) could be easily separated and re-circulated in the system in accordance with cradle-to-cradle principles and focuses on effectiveness rather than efficiency. It also builds on ideas of performance economy with new business models that focus on selling services instead of products to reduce the resource use (Wijkman and Rockström 2012, p. 166).

Cradle-to-Cradle (C2C) is one of the main building blocks in CE. The C2C theory (Braungart and McDonough 2008) claims a natural science background and treats humans as a biological being at a "species" level as other living things, as opposed to, for instance, economic man that treats humans as something outside or beside the natural ecosystems. From this point of view it is clear that the misuse of natural resources is catastrophic for earth and its living systems as well as for future human life.

In the report *World Commission on Environment and Development* (1987) the link between eco-efficiency and sustainability was articulated. This prevailing environmental and sustainability approach of efficiency has, within C2C and CE, been criticized for only focusing on making industry less bad by reducing, avoiding, minimizing, sustaining, limiting and halting. Rather than actually doing things good from the beginning — i.e. effectiveness by restructuring the production system so that it focuses on having a positive impact as opposed to only having a less negative impact. Braungart and McDonough (2008) claim that C2C focuses on eco-effectiveness rather than eco-efficiency.

McDonough and Braungart (2013) argue that the eco-efficiency strategies used for sustainability goals today, are stretching the line but still support the linear production system. "That Reduce, Reuse, Recycle and Regulate are not good enough and puts a negative tone to being environmentally friendly" (Braungart and McDonough 2008, p. 53–61). *Reduction* is indeed needed but it is nevertheless not stopping the depletion and destruction. *Reuse* is only good if the product being reused is not toxic and not releasing toxins during its use. This is true also for reuse and recycling within CE. *Recycling* is in most cases down-cycling; when products that were not designed to be disassembled into different materials will be low quality materials after recycling and might also need additional chemicals in the process to give the sought properties and qualities and thus add toxins to the system. Laws and *regulations* are also claimed to often be an end of pipe solution aimed at minimizing emissions for instance but do not at the same time reward innovative problem-solving (Braungart and McDonough 2008 p. 61). It could even be more dangerous to, for instance, ban one single toxic material in products since it might lead to substitution with not yet banned materials that are even more toxic. This is not common in the real world; however, similar but slightly less dangerous chemicals are often used when one chemical is banned and heavily regulated.

However, they make clear that efficiency can be good, but only when implemented as a tool within a larger, effective system that intends overall positive effects on a wide range of issues — not simply economic ones. It is also seen as valuable as a transition strategy to help current systems to slow down and turn around (Braungart and McDonough 2008, p. 65).

C2C can be seen as an alternative design and production concept, focused on eco-effectiveness; the development of products and industrial systems that maintain and enhance the productivity and quality of materials through subsequent life cycles (Braungart and McDonough 2008). The concept of eco-effectiveness means working on the right things — on the right material, products, services and systems — instead of making the wrong things less bad (Braungart et al. 2006). Eco-effective designers expand their vision from the primary purpose of a product or system and consider the whole. The designer team is supposed to think through what the goals are and potential effects, both immediate and wide-ranging, with respect to both time and place. And what is the entire system — cultural, commercial and ecological — of which this production and product will be part of (Braungart and McDonough 2008 pp. 81–82)?

These ideas applied to our human built processes are the base for three principles in C2C, and CE:

1. *Waste = food*, i.e. that the residue of one process is used as feed/resource in the next process. Nature's nutrient cycles comprise the biological metabolism and the design of technical metabolism mirrors them.
2. *Celebrate diversity*. Ecosystems are complex systems that thanks to diversity enhance a greater adaptability and resilience.
3. Use solar income, the only continuous source of energy.

In the natural cycles of the Earth systems the residue or waste from one cycle becomes nutrients for others. Historically, humans lived more within and connected with nature and the natural cycles at all levels. Humans acted as part of the natural system and respected it in a different way to make sure human waste, both sanitation and made things, became part of the cycles when discharged. Since industrialization and with urbanization, we have, however, distanced ourselves more and more from nature and created non-natural linear flows, cradle to grave, as well as products with hazardous waste as a common side-effect (Braungart and McDonough 2008, p. 93).

Resources and materials can be described as biological or technical, i.e. man made. Biological nutrients can be useful to the biosphere, while the technical nutrients can be useful for what is called the technosphere, the systems of industrial processes. These materials are often mixed however and are, therefore, difficult to re-circulate. Braungart and McDonough (2008, p. 93) points out that we have developed an industrial infrastructure that ignores the existence of nutrients for either kind and have created hybrids of materials that do not fit into either the organic or technical metabolism because they contain hazardous components, and are wasted or lost since the materials cannot be separated after their use (Ibid p. 98–99). Following the principle of waste equals food at design level, producers can make sure that the waste from one product can be reused as nutrients for new products for themselves or other producers in their network.

Ken Webster (2013) emphasizes that diversity increases the resilience of a system. Thinking too much of efficiency implies streamlining processes which will on the other hand result in brittleness of the system since there are so few alternatives if one thing breaks down. Thus, instead of focusing on partial processes, we have to build a system that sees the value of all different flows and the importance of optimizing the whole system and not its parts. Having a built in diversity gives a possibility to adapt to new situations when needed and thus increases the resilience.

In C2C it is expressed that sustainability is local and that respecting diversity includes adapting to the local environment and conditions — regarding material and energy flows as well as local customs, needs and tastes. (Braungart and McDonough 2008 p. 123). Using local sourcing also avoids the problem of bio-invasion — when transfer of materials from one region to another introduces invasive non-native species to fragile ecosystems (ibid. p. 125) — and thereby protects the biodiversity.

Earth's source of incoming energy is the sun, and thereby the fuel for all biological processes. Historically and indirectly even for fossil fuels. The sun is also the motor for other renewable energy sources such as wind and water power. Using different renewable sources of power is seen as an important part of CE (Preston 2012).

Performance and sharing economy is another important part of the CE thinking. One reason to focus on performance rather than commodities is to make it logistically possible for producers to take back and keep technical products in the loop. To ensure that this happens, the notion of product as a service is an important concept since the ownership for the resources then is still kept by the manufacturer (EMAF 2012, p. 111). Another reason is that creating a circular economy implies a shift away from ownership to a new model of collaborative consumerism. This part of CE focuses both on new business models, for example Uber, and product innovation such as driverless cars. The thought is that a shift in consumer mind-set to embrace access to service rather than ownership will hopefully lower demand on new products. Selling a service or performance of a product instead of the physical product would result in a more resource efficient system (Stahel 2010). It is far from obvious that this will be the result in a growing economy, due to the so called rebound effect. Those who had no access before may get it but those who had access will keep their ownership and total consumption would increase.

Sharing economy or collaborative consumption are actions that can be organized between private persons and do not have to involve businesses. The ideas are based on the notion that the ownership of things is replaced by access to the product by "schemes of sharing, bartering, lending, trading renting and gifting" (Botsman and Rogers 2010, p. xv). The philosophy of sharing is based on trust which in itself creates meaning to the user beyond the benefit the product provides (Axelsson 2014, pp. 48–52). This effect and the possibility of new community contacts, add an extra positive aspect to this type of consumption.

Regarding performance economy business models, the same examples are used today as those shown to be revolutionary 20 years ago within the Natural Step (personal communication Markus Larsson). For instance Xerox copying machines, car sharing and Interface flooring. Leasing was promoted as *the* sustainability solution back then as well, which it turned out not to be. Maybe the market and consumers were not ready for it. It will soon show if we are ready now or if we are still too deeply rooted in ownership thinking. Another reason for not succeeding might be that it required complicated administration; administration that is now said to be facilitated by smart techniques. Parts of the solution are there, and have been for a long time, but the development is slow and meeting resistance (personal communication Markus Larsson).

Biomimicry is the methodology of mimicking nature, at all scales. It is defined as "an approach to innovation that seeks sustainable solutions to human challenges by emulating nature's time-tested patterns and strategies" (Benyus 1998).

Biomimicry relies on three key principles (EMAF et al. 2015, Orru 2014-12-17):

- Nature as measure: using ecological standards to measure and judge the sustainability of innovations and designs.
- Nature as mentor: look at nature with the notion of what we can learn from her rather than what we can extract and gain from resources.

- Nature as a model: studying natural systems to have as a model for forms, processes, systems and problem solving strategies.

An example could be to construct buildings with natural ventilation and solar heating inspired by termite colonies or smaller challenges as of how to design and construct a water-repellent material with leafs or bugs as models (Benyus 1998). Building new designs to mimick nature could also imply going back to using techniques that were abandoned for more modern and seemingly efficient methods and materials, for instance (re-)start using soil and plants as a cooling and heating ecosystem on roofs (Braungart and McDonough 2008 p. 83).

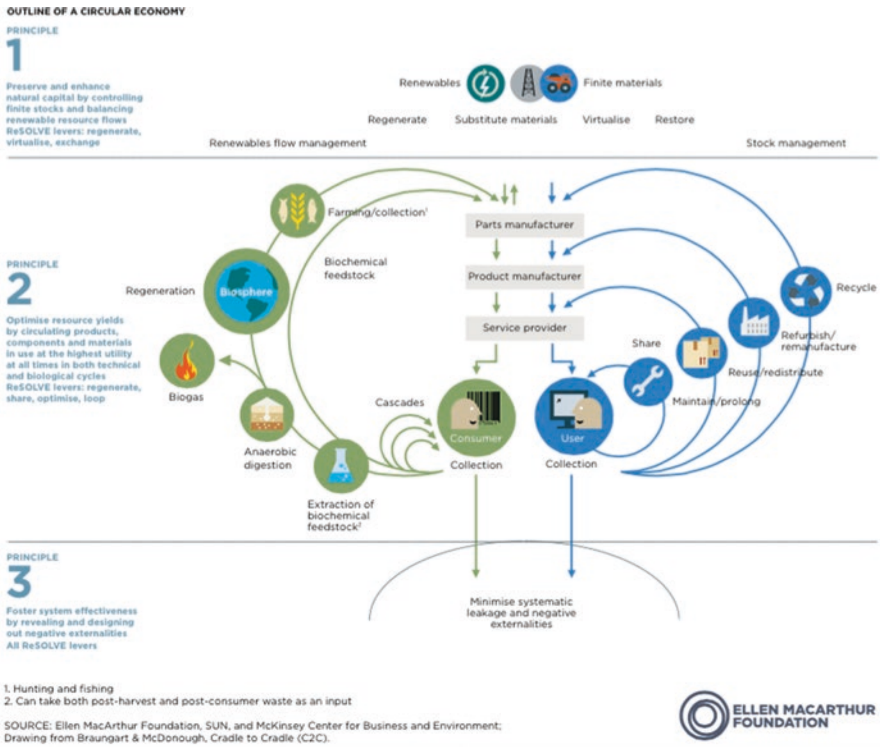

Fig. 11.2 Circular economy with its two systems of nutrient cycles (EMAF et al. 2015) (ReSOLVE refers to: REgenaerate, Share, Optimise, Loop, Virtualise, Exchange. See the full report for further explanation – EMAF et al. (2015) Growth within: a circular economy vision for a competitive Europe)

11.4 Outline of a Circular Economy

Given the different underlying concepts, a circular economy is restorative and regenerative by design, and aims to keep products, components and materials at their highest utility and value, at all times. The concept distinguishes between technical and biological cycles (EMAF et al. 2015). Key characteristics of CE thinking is a holistic approach and systems thinking (Ann-Charlotte Mellquist and Lise Lyngfelt Molander, personal communication).

Figure 11.2 illustrates how biological and technical nutrients should be divided and kept in separate loops in order to maintain high quality and make effective and efficient circulation possible. *Biological nutrients,* to the left, are products or materials designed to be part of the biological cycle — after its product life returning to the natural environment and being consumed by animals or microorganisms (Braungart and McDonough 2008, p. 105). *Technical nutrients*, to the right, on the other hand are materials or products that are designed to go back into the technical cycle, i.e. into the industrial metabolism from which it came (Braungart and McDonough 2008, p. 109). The arrows, or cascades, illustrate that the shorter and smaller the loop obtained, the higher the value kept in the resource and with less addition of energy and other resources to keep it circulating. World Economic Forum discussions on CE further emphasizes the power of; (1) the inner circle, keeping the smallest loops possible, (2) circling longer, (3) cascaded use across industries, (4) pure/non-toxic/easier-to-separate inputs and designs.

11.5 Is CE a Paradigm Shift?

The famous quote by Albert Einstein "*We cannot solve our problems with the same level of thinking that created them*" is an often referred quote in sustainability contexts. Meaning that we have to rethink the whole system that has created the unsustainable system that got us into the problems we have today. Ellen MacArthur and others express that CE is a paradigm shift, a new way of thinking, which can solve many of the problems humanity is facing.

However, it is difficult to see CE as a paradigm shift since most of its components are not new. For instance much of the knowledge needed for sustainability is old knowledge within agriculture and forestry that we have not managed to implement in our modern societies. Within agricultural science the concept of circulation has been around for a long time. When Sustainable Development was put forward at the end of the 1980s, land as a production factor was re-lifted, but it had been an essential part of the economic theory in the eighteenth and nineteenth centuries. It was during the era of neoclassical economic thinking that land, and nature, was dropped as a major production factor. On a macro level it is a rediscovery of the wheel — the circulating wheel. Agricultural and forestry science is about efficiently creating welfare through resources from agricultural land and forestry land. This perspective moved out of focus during the twentieth century when cheap fossil energy made us less dependent on the production factor land (which in economic theory is synonymous to the ecological dimension of the economy) and the emissions were mostly on a local level and generally without a great influence on welfare. Current photosynthesis was substituted by historical photosynthesis saved in fossils. Hellstrand (2013, 2015) and Hellstrand et al. (2009, 2010) analyse this in detail. Rather than seeing CE as a paradigm shift it can be seen as going back to how the economy worked in the eighteenth and nineteenth centuries.

11.6 Circular Economy, and Business Influence

The Circular Economy movement of today is mainly business driven and business focused. Even though many concepts within CE are older, the reframing and merging of them into one CE concept has managed to reach new target groups that were not interested in environmental problems before. Today, CE is very business focused and that's a good thing, since this target group lacked arenas to discuss sustainability innovation and transition. In many businesses today, sustainability is foremost about communicating a result of sustainability on the last row, rather than actually working sustainably throughout the business. Society is in general, punishes business activities instead of encouraging the ones that have a sound base. The industry is not to be seen as "the bad guy", it is politics that has to set the boundaries.

In 2015 a report to the Club of Rome was released, *The Circular Economy and Benefits for Society* (Wijkman and Skånberg 2015). This report, as well as the earlier mentioned report by EMAF, also shows significant possibilities of financial and growth opportunities as well as reduction of carbon emissions and increase in employment. A reason for expressing CE more in terms of financial gains, employment and growth opportunities is to get politicians onboard since politics can help a great deal in taking CE requirements further. This can be done by making sure the questions are formulated so that they become politically relevant to gain impact (personal communication Skånberg).

11.7 Potential — Real or Imagined

There are several crucial issues for the possible success of CE; such as its relation to the present economic system, the imperfect price mechanism of natural resources and the role of government. It has been argued that globally the potential benefits could be as large as $1 trn, mainly because virgin natural resources are more energy demanding than those that have been recovered. Also, it has been argued that business can shift to CE voluntarily since it can materialize the potential benefits and actually increase profits simultaneously by reducing the environmental burden of our production and consumption system. It sounds like a *panacea* or magic bullet — is it really?

Even if many of the CE ideas are not new and more going back to the initial meaning of economy — to economize with resources — they may be new in the way it combines knowledge from different fields and its potential to make an impact on the business and political arena. Thus, if picked up by businesses at a large enough scale, it might lead to a paradigm shift in practice.

The present form of market economy may, however, become a hindrance to success. Maximizing enterprise profit is not the only goal, as is assumed in neoclassical theory. It may already be a problem if a satisfying behaviour is assumed to be the target of business. Satisfying behaviour enables economic sustainability, i.e. revenue is larger than costs in the long run. One important condition is that someone is willing to pay for the goods or services that are produced by enterprises following CE principles. In a market individuals react to knowledge or perceptions about existence and quality of goods and services as well as of their prices. Collective interests they may have as citizens, such as quality of the environment are not expressed very much on the market where individuals express more self-interest. Such issues are better managed through political processes.

Some people are so wealthy they are not affected even if prices are doubled or more, i.e. in practical terms they have no budget restriction. People with such wealth are a minority, albeit growing in numbers over time. They have practically no incentive to save material if prices increase. Inequality is, therefore, not only a problem of fairness but also something which makes it more difficult to reach sustainability. The other resource and environmentally important side of inequality is a pressure on some local natural resources caused by extreme poverty. CE theory and principles lack solutions for social sustainability and addressing these inequity problems.

As relative scarcity gradually becomes a problem, increase in prices of natural resources is one type of incentive to use materials wisely and reuse in order to conserve natural resources as a fundamental part of CE. As natural resources such as minerals are extracted the remaining reserves with high concentrations and that are easy to extract will become smaller. Expected future prices and thereby the value of the remaining resource of equal quality will increase. Owners of such resources should demand a higher price since it is more profitable to keep the resource in the ground and sell it later.

This is in theory, and it may not be the way the real world economic system works. Experience so far is that as long as such resources can be extracted prices do not change in a systematic way. Prices on non-renewable natural resources have been surprisingly stable over time, with some exemptions, e.g. copper. For fossil oil the long term price trend has been decreasing in spite of the fact that we have used a large fraction of existing reserves and we can observe signs of "peak oil". Prices have increased in periods of severe conflicts in the Middle East, including creation of OPEC. This has been as a reaction to lack of supply in the short run rather than increasing long run scarcity. There was an increase in prices for oil, and to some extent for natural resources generally, in the new millennium with a dramatic drop during the 2008 crisis. This trend was broken in 2014 and the prices since then have gone down. Especially, fossil oil prices are very low compared to the rest of the period after year 2000. Overall, the instability has increased over time since 1930.

The lower prices today seem to be caused by a combination of factors affecting supply and demand. Regarding decreased demand factors such as the following examples play a role; (1) stress in the economic system in North America and Europe, (2) a number of policy measures within different policy-areas within the field of natural resource management as well as in totally different policy-areas, for instance trade-measures in the EU and Russia due to the conflict in Ukraine, or changed policies regarding foreign trade for various commodities in China and (3) international conflicts reducing demand from affected regions.

Regarding increase in supply, possible factors are; (1) change of EU-policies related to the common agricultural policy affecting the system of milk-quotas, (2) increase in supply of fossil fuels due to new technology making non-conventional supplies profitable to utilize and (3) the agreement between Iran and the USA giving Iran access to the global fossil fuel market again. The examples above do not represent a complete list, but a few examples of factors affecting prices of natural resources. It cannot be excluded that beneath these factors there is another and new trend operating that indicates an increasing natural resource scarcity to the global economy (Hellstrand 2015).

The fast increase in the use of photovoltaic elements is due to technological innovation in combination with high prices on fossil oil during the last 10 years. The search for alternatives is stimulated by the threat of climate warming.

There is likely to be dramatic price increases on some natural resources in the future when it, due to scarcity, becomes difficult to supply the markets with demanded quantities. This may however be much later than is needed to stimulate CE in the form of cradle-to-cradle design.

The possible role of government is an important issue in relation to CE. In some of the literature the role of government is played down with expectations that business will see potential benefits and by themselves do the right things. Others are aware of the need for governmental policies. We are clearly in favour of the latter view. There is no socioeconomically advanced society that does not have a functioning state sector. Also, the socio-economic systems that score highest on welfare indexes of various kinds are the Nordic welfare states that have relatively high taxes and a relatively large state sector.

Wijkman and Rockström seem to be aware that there is a need to supplement the ideas in CE with regulation.

> Today we need to couple the advantages of an open and globalized market economy with regulations that enable consumers and producers worldwide not only to be more efficient in general in their use of natural resources but also effective — that is, to do the right things. Wijkman and Rockström (2012, p. 169)

There are problems in combining a market economy operating over national boundaries with a number of nations having unique sets of regulations. Global enterprises can even put pressure on small nations not to regulate by threatening to move to other countries. The examples of effective and well working international regulations in the area of environment and resource conservation are few despite the large need and many efforts made.

The possibility to collect and reuse materials in a safe way is crucial for the functioning of CE. Today, in some countries the level of recycling reaches 50–95% for some material flows. There is no doubt that this could be achieved in most well organized countries and with a few more flows as well. There is, however, a limit to how many different fractions consumers can separate waste flows into. In the cases where recycling is successful, there is policy to support it. Deposit-refund systems are one type of system; where consumers pay a fee when they buy a commodity or packaging/container, e.g. a glass bottle, and are refunded when returning the commodity or packaging/container. Such systems could be organized voluntary by the provider of the goods but are normally a result of legal demands.

Another solution is to put legal demands on producers to be responsible for the goods when they enter the waste stage. This is used in Sweden and the result is that producers organize a collective system to collect, transform and reuse the material. This solution does not give incentives to individual producers to make sure the purity of materials used is such that there is no danger in reusing the material in other uses where quality demands are higher. To achieve that there is a need for responsibility for individual retake of "their" material, but that would be much more expensive in terms of organization and transport. This is not necessary for homogeneous material flows where there is little risk of content of dangerous chemicals. There is, however, a risk that dangerous chemicals can be spread in the environment causing health problems if material streams are not "clean".

Once a company has the material in a more or less pure form there may very well be profits in reusing it. What is the incentive for consumers to sort waste and return the things they do not use to the company which has sold it?

It would take a lot of effort to return each commodity to the seller or producer of that commodity. If it is collected in a mixed stream there may be a need for sorting which might be expensive in terms of labour time and it may still not be safe. The number of different commodities in circulation in a modern society is enormous. Also, for an individual consumer there are many companies that they buy from. For large and relatively homogenous flows, such as wood and cotton or iron and aluminium, the possibility to organize collection and reuse is good. For more complex commodities this becomes much more difficult to do.

For flows of biomaterial, which of course should be kept separate from industrial flows, it is important to keep the purity on such a level that they could be safely returned to and used in the various forms of bio-production. The most critical issue may be the concentration of dangerous chemicals. There are other impurities that are not dangerous for soils or bio-production.

In some cases, the issue is not that of dangerous chemicals but rather the mere quantity of flows, e.g. various forms of plastic. Plasticisers, e.g. phthalates, or repellants, e.g. perflourated carbonates, make the plastic into dangerous commodities, but even without such additional substances plastic poses some danger to the environment. It will be very difficult to make consumers not demand the products with special qualities and properties that depend on the use of some dangerous chemicals, if the decisions are taken individually on a market; and for the producers to stop using the same chemicals if there is profit to be made.

It is very unlikely that the needed systems for reuse of materials will appear without the influence of policies to give consumers incentives to do the right thing. The potential of $1 trn is more a theoretical maximum than something that could actually be reached in the real world. Creating and enforcing a policy has a cost that must be included in an economic calculation. Generally, a policy for increasing the costs of using energy based on fossil fuels is a must in order to give incentives for substitution and reduced energy use. Higher prices on fossil fuel would have many implications for resource conservation in other fields as well.

The business model of leasing or selling services instead of products is said to give incentives for the businesses to keep the products longer but it may have a negative side. There is a risk of increased power for businesses if we at a higher degree buy services and performance rather than products. If companies own durable goods in our homes, inventories at other companies or public places, people tend to become more dependent; thus losing power. Also, there is a risk that centralized power in digitalized sharing platforms will create monopoly which is less flexible and creates new power structures. This may have negative social impacts. The digitalized sharing platforms may create societal benefits and profits for the owners of the platforms but give little gains for the other actors on this market.

A policy for increasing the costs of using energy based on fossil fuels is a must in order to give incentives for substitution and reduced energy use.

CE may not be a *magic bullet* or *panacea* but it involves several good ideas that can be used to improve our society. The challenges to reach sustainability may be more difficult to overcome in the societal and economic spheres than in the biological and technical spheres. We should see CE as a process or approach to solving our problems rather than a ready to apply solution. In a clever combination with policy, Circular Economy could be an important step forward.

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E. Dahlquist, S. Hellstrand (eds.), *Natural Resources Available Today and in the Future*, DOI 10.1007/978-3-319-54263-8