CHAPTER SAMPLER

Sustainability in Engineering

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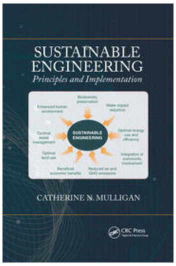
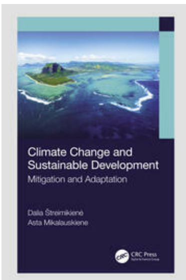
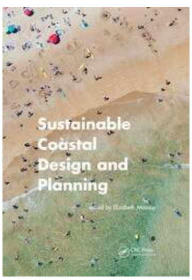
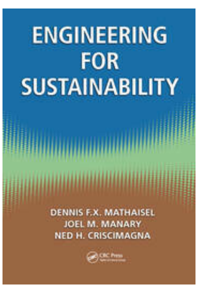
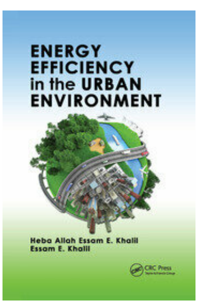
Contents


SUSTAINABLE ENGINEERING
Principles and Implementation
SUSTAINABLE ENGINEERING
CATHERINE N. MULLIGAN


Climate Change and Sustainable Development
Mitigation and Adaptation
Dalia Štreimikienė
Asta Mikalauskiene


Sustainable Coastal Design and Planning


ENGINEERING FOR SUSTAINABILITY
DENNIS F.X. MATHAISEL
JOEL M. MANARY
NED H. CRISCIMAGNA


ENERGY EFFICIENCY in the URBAN ENVIRONMENT
Heba Allah Essam E. Khalil
Essam E. Khalil

8

Implementation of Sustainable Engineering Practices

8.1 Introduction

Sustainability has gained significant attention in the past decades, particularly by engineers. The definition of sustainability by the Brundtland Commission in the 1970s, however, is quite vague and difficult to implement. More recently, tools have been developed to assist in integrating sustainability into design, particularly for buildings and infrastructure. None of these has been adapted universally. In the 1970s, environmental considerations became important. Now, aspects such as resource conservation, societal acceptability, energy minimization, use of renewable energies, and mitigation of climate change, among others, must be included in project/process/system considerations. This chapter will provide examples of sustainable engineering practices and challenges and needs for the future education and research.

8.2 Integration of Sustainability Concepts into Engineering Practices

According to the Association of Consulting Engineering Companies (ACEC)—Canada report on consulting engineering and sustainability (Boyd 2016), conservation, preservation, prediction, and consultation are four main aspects to be included in engineering design. Conservation includes minimization of water, energy, and materials by recycling or use of renewable energies. Durability and site restoration after decommissioning must all be included in the planning. Environmental laws must be followed for biodiversity preservation and health and safety. Human rights must be respected and climate change impacts must be considered. Cultural considerations are also becoming more important. Prediction involves designing for resilience in a changing environment mainly due to climate change. Affected communities must be consulted, as they are important stakeholders in projects.

Climate change is another very important challenge for sustainability. There are two main approaches, mitigation and adaptation. Mitigation involves the reduction in carbon dioxide emissions, in particular. This can be related to reducing energy use, using cleaner fuels, and possible carbon capture. This applies to transportation, buildings, industry, and environmental remediation such as waste management. Adaptation involves new design for projects, as historical data will not apply. Greater uncertainty and thus large factors of safety will be needed.

Clients are becoming more interested in sustainability. Many companies are now participating and producing sustainability reports using the Global Reporting Initiative (GRI) as seen in Chapter 6. Many government agencies also have committed to sustainability. Public participation has been mainly during the environmental assessment phase of a project. This is usually late. They need to be included from the concept of the projects to uncover issues and to communicate progress to the stakeholders.

Procurement also needs to be included in sustainability. This includes no sweatshop labor or unfair labor practices or corruption, use of fair trade products, and support of local development. Engineers must improve sustainability of projects and processes for the future. Determination of indicators at an early stage of the project in consultation with stakeholders is essential. The engineer has the most influence in the early stage of the project. However, there are opportunities during commissioning, operation, and decommissioning to improve sustainability. Climate change is also causing more uncertainty in designs. New tools can help. Traditionally, projects have to meet the client and regulator's requirements. The society is adding new requirements for the project in terms of sustainability. Engineers have an ethical requirement to face these new requirements. New tools are being developed to assist in the assessment but none is perfect. For example, LEED and BREEAM are restricted to buildings.

Innovation is a key aspect for sustainable engineering. These projects are riskier and require more time initially. However, payoffs will be in the future with reduced operating costs. According to the World Federation of Engineering Organizations (WFEO 2015), engineers can contribute to sustainable practices in many ways. Some of these include harvesting renewable resources in ways to ensure continuous supply, minimization of nonrenewable resources, processing resources with little to no wastes, designing and building of infrastructure and processes with minimal waste and environmental impact throughout the life cycle, and development of clean renewable energy sources. Human needs must be met for ensuring adequate living and health standards. In other words, sustainable engineering involves the use of natural resources in a cost-effective way for the support of the human and natural environments. The approach should be as close to a closed loop as possible as proposed in the circular economy. In Chapter 5, various sustainable practices for resources, environmental restoration, and energy production and use were discussed. The next section will demonstrate some case studies of sustainable engineering practices.

8.3 Examples of Sustainable Practices

8.3.1 Industrial Park in Haiti

In Haiti, the construction of the Caracol Industrial Park was to take place. This was to be one of the most important infrastructure projects in the country. When it came to the production of a drinking and industrial water production facility, the mandate for the turnkey project was removed. At this moment, the engineering consulting company SNC-Lavalin took the initiative to design the plant.

Initially, a designer with little experience in working in developing countries, proposed a reverse osmosis system to remove components from the groundwater such as manganese. However, this option was very energy intensive, particularly for a country that gets 95% of their energy from diesel or fuel oil. In addition, the maintenance and operation of the system would be very difficult. The proposed solution was an ion exchange system. The resins would eliminate water hardness and other elements such as manganese that gives color, bad taste, and toxicity, if the water is consumed over a long period of time.

The advantages of the system included:

- The process consumed 98% less pumping energy than reverse osmosis that requires high pressures. The process did not include any mechanical parts such as motors or gears that would have to be replaced due to use.
- The process included the local community in the village of Caracol that already had a salt production system from sea water (Figure 8.1) that was necessary for the recharging of the anionic resins; in other words, the village found a new market for their salt for the system that would require 4 metric tons/day for the production of the water.

When the plant was designed, all equipment was selected so that it could be mounted or moved by an overhead crane of 5 metric tons. In other words, the bridge was able to accommodate the 19 pumps and 10 reservoirs for the softening as well as the 1 metric ton bag of salt for the plant and move them directly by a truck of van without the need of a crane or other equipment. The project was started in 2011 and inaugurated in 2012.

FIGURE 8.1
Production of salt in the village of Caracol (satellite view).

The project consisted of:

- A 400 m^2 building
- Water treatment for drinking (6,000 m^3/day)
- Water for industry (6,000 m^3/day)
- Water for firefighting (2,160 m^3/h)

The system consisted of a phase 1 water treatment reservoir (drinking) of 500 m^3 and one for industrial water of 1,500 m^3. The disinfection was by chlorination (available locally with two peristaltic pumps for 24 h use). The cost was US $3,000,000 for the drinking water production. The design period was 50 h for the preliminary design and 200 h for the detailed design.

8.3.1.1 Environmental Aspects

The process conformed to the rules and regulations of the World Development Bank. An environmental assessment, environmental management plan, and management of greenhouse gases (GHGs) were all according to the norms of the World Development Bank.

The technology used 98% less electricity from heating oil generators, 2–5 MWh of energy for 500 m^3/h of water. This reduced the production of GHGs. The pumps have their own frequency regulator that reduced their energy at start-up and optimized their continuous operation. Translucent panels were used for the panels of the building, thus reducing lighting requirements.

Ventilation and temperature control were ensured by 10 cm (4 in.) vertical spaces between the panels. All wash water was recuperated and sent to the treatment. None was sent to the stormwater drainage system. The water from the softening systems was high in hardness. This was beneficial for the industrial plant that required high alkalinity for its coagulation/flocculation process. A landfill according to the norms of the World Development Bank was built and all buildings had their own septic system along with infiltration fields.

The process did not produce any dangerous wastes. Disinfection was by chlorination. The peristaltic pumps were able to pass ten times higher concentrations of chlorine than regular dosage pumps and thus lower volumes of stored solution and less handling were needed. They did not produce noise.

8.3.1.2 Social Aspects

Salt was purchased from the local community at a rate of 4 metric tons/day. A social impact study was performed according to the norms of the World Development Bank. Six offices of the six neighboring communities were organized to manage the hiring of personnel and favored hiring from the local region. Twenty percent of the construction workers were female, which was a first in Haiti, where normally 0.5% is female. Efforts were also made for deploying social responsibility, conserving cultural sites, avoiding negative social impacts, and supporting the neighboring communities as performed by the World Development Bank and client.

8.3.1.3 Economic Aspects

The plant was to employ 3–5 local people as technicians and chemists. The salt production needed up to 50 employees. Others were needed to transport the salt. Therefore, all created employment opportunities for the local community. In addition, the reduction in energy will save energy costs.

8.3.1.4 Ethics

The project was designed with the concept of sustainability. The building was well lit and ventilated, local salt was used in the production, a crane was used to move the equipment, and the project produced essential water for drinking, industry, and firefighting.

8.3.2 Case Study of the London 2012 Olympics

The London 2012 Olympics was proposed to ensure sustainability in the design, building, operation, decommissioning, and reinstatement of infrastructure (ODA 2013). Sustainability was integrated into the design, procurement and contract management, planning, building, and operation phase along the lines of biodiversity, energy, environmental impact, materials, water, and waste.

Strategy development was the first phase. The vision can be seen in Figure 8.2 along the lines that leave no trace (no environmental damage), zero waste to landfill (reducing waste and maximizing reuse/recycling), zero harm (no accidents, injury, or incidents), and leave a positive legacy (environmental, social, and economic).

The infrastructure was quite unique in that it was temporary so there were no other examples to base the procedures on. Table 8.1 shows the priority targets and outcomes. Success factors were identified such as securing committed leadership, embedding sustainability in procurement and contracts, establishing, monitoring and reporting key performance indicators, and reviewing all audit processes such as environmental management plans.

To deliver the strategic vision and targets, four areas were identified. These included sustainable design, procurement and contract management, town planning, and building and operations.

Sustainable design procedures and results included:

- Establishing a working group for design
- Developing guidance for technical specifications
- Working with suppliers to review products and materials

FIGURE 8.2
Strategy and vision for sustainability for London 2012. (Adapted from Aukett [2012].)

TABLE 8.1

Priority Targets in Sustainability Planning for the London 2012 Olympic and Paraolympic Games

Objective	Final Outcome
Reduction of carbon emissions and minimization of carbon footprint through hiring 85% of commodities to reduce embodied carbon	86% reached
Reduction of venue footprint by 25% to reduce need for materials, air conditioning, lighting, etc.	47% reached
Reduction of heating, ventilation, and air conditioning (HVAC) cooling by 70% and maximization of natural cooling to reduce energy, carbon and GHG emissions	82% reached
Minimization of particulate matter by 80% to improve air quality	90% reached at 47 generator sites
Purchase of at least 20% of materials that are recycled or from a secondary target to reduce material and carbon impacts	Could not be determined
Reuse and recycling of 90% of materials from installation and deconstruction of facilities to reduce wastes	99% reached

Source: Adapted from Aukett (2012).

- Reducing need for extra ventilation and cooling
- Designing standard modules to reduce waste

Procurement and contract management steps consisted of:

- Introducing sustainability ambitions to suppliers in the expression of interest phase
- Pre-ITT (invitation to tender), initial discussion on sustainability considerations at meeting
- ITT phase 10 sustainability questions required responses
- ITT review, Sustainability Procurement Check Sheet completed
- Contract award, sustainability credential needed by suppliers.
- Contract development, sustainability policies, and procedures embedded in the contracts
- Contract management framework and audit tool used to track sustainability

Communications and negotiations were essential to address challenges, particularly of technical versus sustainability, and time issues. Sustainability requirements were often overwhelming for suppliers. Lack of information on the suppliers' own products required training.

Town planning required environmental impact, protection, and management plans to be implemented. Environmental Impact Assessment

(EIA), surveys, and impact assessments had to be performed in consultation with regulators, stakeholders, and planners. Keeping track was essential, all had to be done for a short-term event that presented special challenges. Regular meetings were required. Many surveys were available for land already.

The process for managing impacts and risk at the operations phase included management of environmental risks (air and water quality, noise, ecological preservation), management of waste and resources for reduction, reuse and recycling, and contractors were required to operate sustainably. Stakeholders engagement was ensured at different levels (close engagement, consultation, and information, or information only). Compliance auditing was undertaken on a regular basis; issues and incidents were managed and reporting from all suppliers was required.

Some of the overall conclusions and accomplishments included:

- Clear vision and approach on technical information, such as presence of carbon footprint, are needed.
- Strategic approach needed to be developed for all aspects.
- Budget and resource needed to be addressed early.
- Targets needed to be prioritized and reviewed.
- Design teams and suppliers should be engaged and challenged to improve performance.
- Support is needed for many suppliers and many now have new skills in sustainable practices.
- These lessons although taken for a unique event can be used for many projects.

Various microreports are also available online providing more detail on the sustainability of various aspects of the Olympic Games. For example, an evaluation (ODA 2011) was performed by the design teams to determine which type of pavement would be more sustainable. Asphalt, poured concrete, permeable asphalt, block paving, and porous gravel were some of the options considered. The unit for comparison was one square meter of paving.

The criteria for comparison based on the Building Research Establishment Green Guide Specification included:

- Embodied carbon dioxide
- Recycled content
- Recyclability at end of life
- Weight of materials to reduce handling risks
- Avoided carbon dioxide by recycling

- Urban heat island effect
- Pavement depth
- Olympic Delivery Authority (ODA) green guide specification rating

Other aspects included aesthetics, buildability, cost, wet weather performance, and vehicle loading. Conclusions were reached that despite the high-embodied carbon dioxide content, asphalt was more sustainable due to the requirement for less material. Less depths were needed that reduced the material requirement. The tool CEEQUAL was useful for optimizing material use and energy. Increasing the content of recycled material increased sustainability. It provided a central location for information for discussion by stakeholders and enabled maximization of sustainability using several elements.

Under a contract from the ODA, all the civil engineering, landscaping, and public realm works at the Olympic Park were assessed and verified using CEEQUAL in 17 separate package assessments, all achieving 'Excellent' rated awards. These individual assessments included the Enabling Works (North and South Areas), the Landscaping and Public Realm in the South and North Parks, the District Heating and Cooling Network, Overbridges and Stadium Bridges, and the Primary Foul Sewer and Pumping Station. The scores from the individual assessments were aggregated on a construction value-weighted basis, giving an overall weighted 'Excellent' CEEQUAL score of 93.8%. Furthermore, two of the 17 Olympic Park projects achieved very high scores of 98.3% for the CEEQUAL Assessment: Olympic Park North Park Structures, Bridges and Highways (SBH Lot 1) and Olympic Park Wetland Area Bridges.

8.3.2.1 Economic Activity

Overall, in creating the Park, 2.8 million U.K. construction professionals were involved and over 4,000 long-term jobs were created for the new technology, design, and research center. They generated due to the 4 million visitors during the summer and another 800,000 visitors per year will visit the swimming center. A total of 8,000 new homes, 12 new schools and nurseries, 3 health centers, and a new library were planned after the Games. Two million metric tons of heavily contaminated earth was remediated in addition to the regeneration of the River Lea through the Park. More than 6.5 km of waterways will be monitored in the park. Efforts toward enhancing wildlife habitats incorporated bat roosts, frog ponds, kingfisher walls, otter holts, and planting of wild flowers. Features such as LED lighting, photocell switches, efficient fixtures, and the irrigation system fittings were employed for reduction of energy requirements. Renewable energy production onto the grid included wind turbines and photovoltaic cells for the lighting columns. Overall, 98% of Olympic Park demolition work materials were reclaimed for reuse and recycling, and greater than 650 bird and bat boxes were installed across the Olympic Park (ODA 2013).

London 2012 was the first Summer Olympic and Paralympic Games to measure the carbon footprint over the entire project (CEEQUAL 2013). It showed that by using an independent sustainability assessment tool like CEEQUAL planning, executing of projects and maintenance work during operation can be influenced to enhance sustainability practices.

8.3.3 Sustainable Remediation Using GOLDSET

Various tools can be used such as carbon footprint, ecological footprint, energy efficiency, and life cycle assessment (LCA) but these cover only the environmental aspects. Some multicriteria analytical ranking or scoring systems such as GOLDSET (Golder Associates 2018) are available that cover all three aspects. An example of this is provided as follows:

The GOLDSET-CN approach includes project description and determination of alternatives. Selection of the appropriate indicators, evaluation of the options by data entry and selecting scoring and weighting and finally interpreting the results and recommendations as shown in Figure 8.3. The process can be done across the project life cycle as shown in Figure 8.4.

FIGURE 8.3
Five-step process using GOLDSET (Golder Associates 2018).

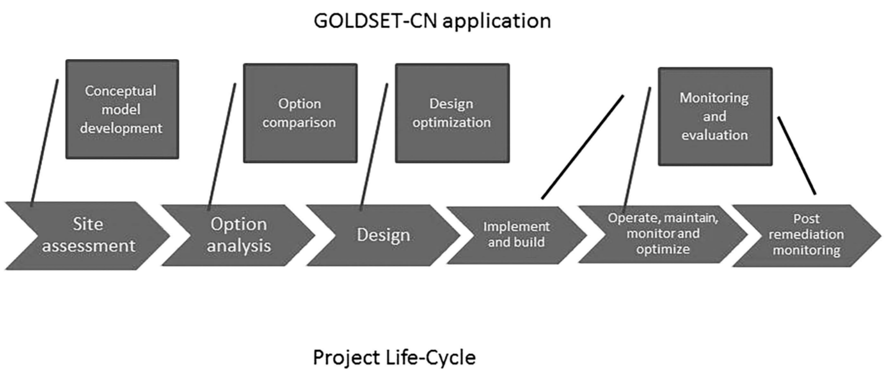


FIGURE 8.4
Application of GOLDSET-CN across the project life cycle (Golder Associates 2018).

A case study was undertaken on the derailment of a train in a peat bog in the province of Quebec in Canada. About 280,000 L of petroleum, which was mainly diesel, spilled and impacted 12,000 m^3 of peat and soil in a ca. 7,000 m^2 area that was 2.4 m in depth. An emergency pumping of the fuel from the water was performed, the train cars were removed, and a confinement trench was installed. The bog was ecologically sensitive and the local community considered it to be an ecological reserve. Three options were evaluated: natural attenuation, partial excavation with risk management, and complete excavation. Indicators were then selected. Estimates of energy and emissions of GHG were calculated in the GOLDSET module as shown in Table 8.2. Scoring and weighting were then performed, as shown in Table 8.3.

Stakeholder involvement was a key part of this sustainable remediation framework. University research leaders as well as members of the regulating

TABLE 8.2

Sample Indicators and Benchmarks Set for the Case Study

Indicator	Unit	Period 6	Period 7	Planned at Completion	Accepted Variation (%)
Soil quality	m^3	0	0	600	10
GHG emissions	total CO_2 eq.	0.18	0.54	47.17	25
Energy consumption	GJ PFE	2.68	8.22	647.7	25
Hazardous waste	kg	0	400	5,730	50
Impacts on biodiversity	—	45	45	90	
Energy consumption per cubic meter excavated soil	GJ PFE/m^3	0	0	0.83	15
GHG emissions per cubic meter excavated soil	Total CO_2 eq./m^3	0	0	0.06	15

TABLE 8.3

Sample Indicators Scoring and Weighting (Golder Associates 2018)

Economic Indicator	Natural Attenuation	Partial Excavation and Risk Management	Total Excavation
Remediation Option			
Net present value	0	100	100
Potential litigation	90	90	100
Financial recoveries	75	50	25
Environmental reserve	100	100	100
Economic advantages for local community	0	50	50
Technological uncertainty	0	50	100
Logistics	100	50	0

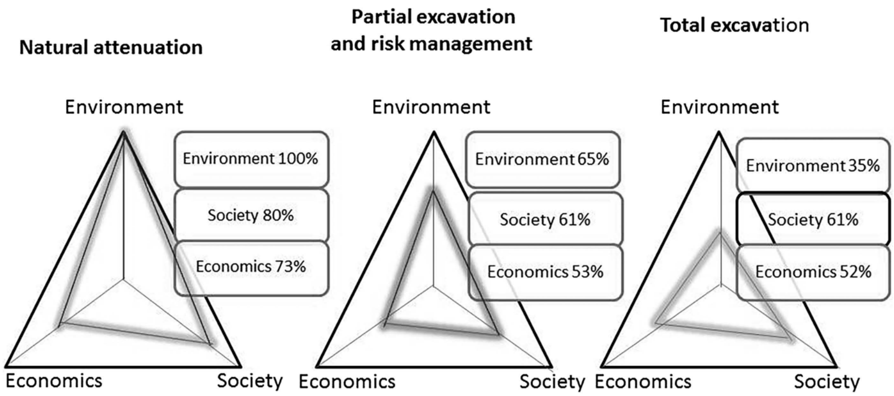


FIGURE 8.5
Comparison of remediation options using Goldset-CN for derailment in a peat bog. The most balanced shadowed triangle indicates the most sustainable option.

agencies were invited to contribute to weigh in on the issues at hand, and provide pertinent comments and questions. These key stakeholders contributed to the composition and procedural design of expert reviews, which helped ensure that all stakeholders found the results of this process credible.

The remediation scheme chosen involved partial excavation and *in situ* remediation. Despite the sustainability of natural attenuation, the regulators did not accept this option. Special floating walkways were installed to access the pilot plots to minimize impact on the vegetation. Solar panels were used to reduce GHG emissions for the blower. Truck-mounted equipment was replaced by tripod mounted or manual augers to reduce vegetation damage. The local university provided expertise to restore the peat bog. Excavation and transport were reduced which in turn reduced 250 metric tons of carbon dioxide emissions. Local landowners were kept informed which enabled participation and acceptance.

GOLDSET provided a transparent communication tool (results shown in Figure 8.5), and enabled the evaluation and tracking of sustainability indicators over the life cycle of the project. Environmental, social, and economic performance can be enhanced by this process.

8.4 Future Needs

8.4.1 Role of Education

Education programs have introduced the sustainable development concepts in to courses to undergraduate engineering students. An industrial survey in 2013 indicated that energy use and efficiency, recycling and reuse, life cycle analysis and corporate social responsibility are key educational needs (Fergus et al. 2013). Special courses have been developed and sustainability has been integrated into course material. Specialization in sustainable development in new degrees may also be another option. Integration of sustainable practices in courses has been difficult as some lecturers are opposed and others are not trained how to do them. Environmental aspects are more easily integrated than social and equity issues. Real-world cases (Steiner and Posch 2006) are required to demonstrate the interdisciplinarity and transdisciplinarity in a complex problem-solving environment. This approach provides a better, dynamic, and more sustainable learning environment.

Sustainability has also become a requirement of engineering program accreditation. In the United States, Accreditation Board for Engineering and Technology (ABET) indicates that students must be prepared for aspects of professional practice that includes sustainability among other aspects. Graduate attribute mapping where learning outcomes are determined and tracked is becoming more popular internationally. Guidance to integrate sustainability in course curriculum is still lacking. Sustainability goes beyond the environmental aspects currently in many courses. In Canada also, Engineers Canada, the national organization of the 12 engineering regulators that licenses Canadian members of the profession, expects graduates to have various skills. This includes understanding of the interactions and the uncertainty of engineering on the economic, social, health, safety, legal, and cultural aspects of society. Some organizations such as Engineers without Borders USA (www.ewb-usa.org) exist in various countries (almost 50) and involve professionals and students for executing projects in developing countries to ensure that the water, sanitation, energy, and infrastructure needs for the communities are met.

Education is key to training future engineers in sustainability. This trend toward interdisciplinarity in engineering education is reflected by an increasing number of interdisciplinary sustainability initiatives at universities and research institutions (CAGS 2012; De Graaff and Ravesteijn 2001). In Canada, a prime example is the University of Victoria that has been the recipient of funding for its *Training Program in Interdisciplinary Climate Science* (University of Victoria 2017). The University of Toronto has applied an interdisciplinary approach to identifying the role of engineers in solving complex global problems—including those related to sustainable development—at the *Centre for Global Engineering* (CGEN) (University of Toronto 2009). In its *Cinbiose* interdisciplinary environmental research centre, *L'université du Québec à Montréal* (UQAM) has collaborated with the World Health Organization since 1998 on problems in several fields such as health care, ecosystem dynamics, urban ecosystem governance, and climate change (UQAM 2017). Western University offers graduate-level courses on interdisciplinary approaches to sustainability studies, and also maintains a standing research faculty contributing to sustainability research across 33 different academic disciplines (Western University 2017).

In the United States of America, initiatives in multidisciplinary environmental research are well established. Stanford University's *Precourt Energy Efficiency* Center (Stanford University 2016) is an example. Universities by setting curriculum standards have the moral responsibility to educate their graduates to play a crucial role in developing a socially just, ecologically aware, and economically responsible society. At the same time, engineers have the obligation to develop and implement design, construct, and manage techniques that minimize environmental and energy footprints. In addition, engineers must also be able to work in multidisciplinary teams that incorporate perspectives from public policy, economics, and social responsibility. These demands place a unique burden on engineering educators to design programs that will train engineers for future challenges.

Engineers must be able to work in multidisciplinary teams incorporating public policy, economics, and social responsibility (Figure 8.6). In light of the above, Concordia University has established the Concordia Institute for Water, Energy, and Sustainability Engineering (CIWESS) that provides a unique interdisciplinary training in water, energy, and sustainability engineering (concordia.ca/ciwess). The specific objectives of this training program are: to catalyze through collaboration, internships, enhanced research opportunities in sustainability; to train highly qualified personnel in an interdisciplinary manner for public, parapublic, and industrial sectors; to maintain and enhance interdisciplinary areas of teaching and research; and to attract external research funding and foster relationships with external researchers and internal Concordia researchers with similar interests.

The training program (Mulligan 2017) is producing trainees with unique knowledge and skills related to sustainable water and energy systems through a combination of multiple programmatic pathways, such as undergraduate minors, graduate degrees and courses, capstone courses, research seminars, internships, conferences, and public outreach.

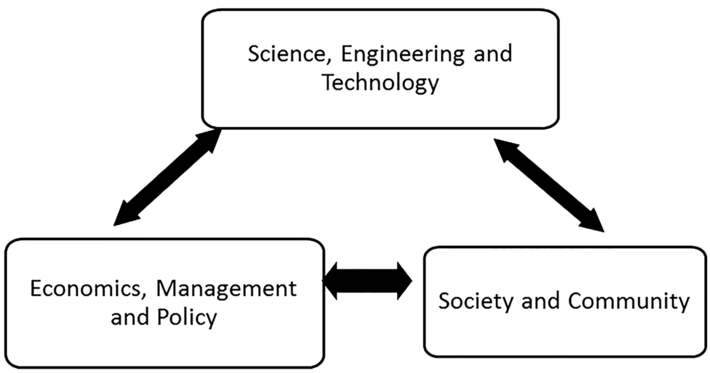


FIGURE 8.6
Interdisciplinary aspects of the training program.

Since interdisciplinarity is an essential prerequisite of any type of research related to sustainability, this program incorporates it at the level of content and program. The underlying philosophy of interdisciplinarity of the program is revealed in the schematic representation in Figure 8.7. All research content while being grounded in scientific and technological aspects nevertheless incorporates economic/policy and society/community aspects. A key mechanism to facilitate interdisciplinarity in research content is through the constitution of supervisory committees that will include members from all aspects.

Since environmental and social issues are by their very nature complex and interrelated, students are required to cross disciplinary boundaries in order to collaborate with those in other disciplines. Interdisciplinary collaboration requires skills that demand modifying traditional ways of thinking and being open to novel means of cross-disciplinary communication. Internships are provided to allow trainees to work in the modern collaborative workplace to improve their academic and professional strengths

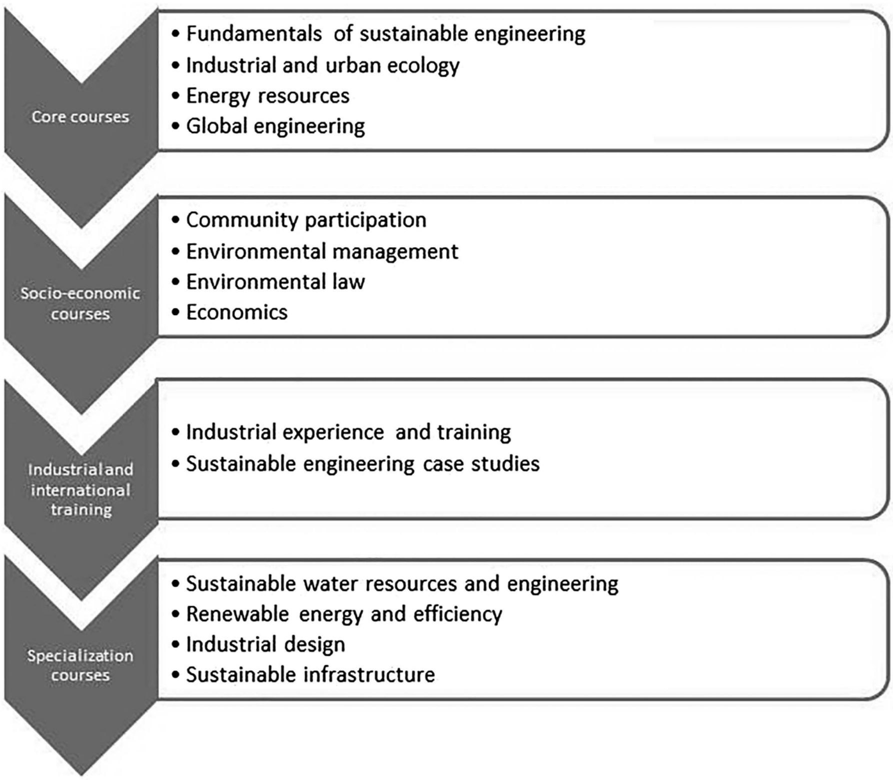


FIGURE 8.7
Components of sustainable engineering graduate programs.

and acquire program-relevant work experience. They gain important soft skills (communications, teamwork, interpersonal cooperation) essential in today's work environment, learn more about the expectations and needs of employers, develop independence and maturity, and take advantage of networking opportunities. The skills obtained enable students to work in policy development, governmental agencies, international organizations, industry, and nongovernmental organizations (NGOs). An internship is a required element of every trainee's program. An annual research event showcasing the achievements of the program provides a venue for trainees to present and discuss their work.

The program facilitates these collaborations by integrating opportunities that arise from these research exchanges into training. In addition, by enhancing international exposure these collaborations will foster globally sustainable work practices in trainees. For example, trainees develop international expertise through these collaborations in water-related disciplines as water engineering and management, land use planning, or water environmental studies.

Trainees are required to attend workshops and professional skills training. These workshops enhance the ability of trainees to write and present effectively, to plan and manage projects, to study abroad during exchanges, to understand ethical practices, and to speak in another language. Another integral component is an internship completed under the supervision of an experienced engineer/computer scientist in the facilities of the participating company. In addition, the university allows trainees to work full time for 4 months at the industry. This structure allows students to maximize the experience of working in teams, develop presentation skills, and the ability to prepare written reports and other information.

Training and education programs are essential for increasing the ability of engineers to address the Sustainable Development Goals (SDG) targets. Innovative initiatives across educational institutes should be shared. Industry, government agencies, and academia need to work together developing and promoting innovation and new ways of thinking.

Informing the public is also an essential element that universities need to include, particularly in their research programs. For example, in a research project in CIWESS, residents involved in lake associations are consulted and information of the development of technologies to maintain and improve lake quality to enhance engagement is provided on a regular basis. Solutions for waste management also must involve the public to incorporate, adopt, and maintain new technologies. Training programs for operators and other personnel are essential.

In a workshop hosted at Concordia University (Montreal, Canada June 9, 2016) with Polar Knowledge on waste management and waste to energy solutions for northern communities, there were discussions of the feasibility of different waste to energy (W2E) solutions for communities of different sizes. Community size was an important factor. Namely, the solutions for waste management and W2E are different for small communities [<500 residents] compared to medium [500–2,000 residents] and large communities [>2,000 residents] in the North. For medium and large communities, landfilling best practices, compaction, composting, incineration or gasification with heat recovery, or refuse-derived fuel (RDF) boiler. For small communities, options include landfilling best practices, compaction, and incineration with heat recovery.

Key aspects for waste management solutions include education, training, buy-in from the community, and to keep trained the community members in the community. Availability of parts and maintenance can be major challenges in remote communities. Community engagement with project planning/design is essential.

8.4.2 Role of Engineering Organizations

Various engineering organizations have formed sustainable development committees to inform their members regarding sustainable engineering and have formed guidance documents. Some of these are by the American Society of Civil Engineers (ASCE) and the U.K. Institute of Civil Engineers (ICE) and the Canadian Society for Civil Engineering (CSCE). The Committee on Engineering and the Environment enables WFEO and the global engineering profession to support the achievement of the UN Millennium Development Goals through the development, application, promotion, and communication of:

- Environmentally sustainable engineering practices and technologies
- Adaptation of infrastructures to the impacts of a changing climate
- Assessment and promotion of clean technologies and engineering practices to mitigate climate change
- The engineering perspectives on the international elements of the agricultural supply chain to United Nations agencies and commissions, national members of the Federation, and other international NGOs
- Development of guidelines for practicing engineers on responsible environmental stewardship and sustainable practices in various areas of practice including mining

The WFEO represents more than 20 million engineers with extensive expertise to contribute to the achievement of the UN Sustainable Development 2030 Goals (WFEO 2015). Engineers must work with organizations, other experts, governmental organizations, and the communities to develop technologies, policies, and frameworks. Engineering societies in many disciplines must also work together toward sustainable engineering. Sharing of case studies can assist in promoting and understanding sustainable practices and implementation. The WFEO Model Code of Practice for Sustainable Development and Environmental Stewardship (WFEO 2013) was developed and adopted at the September 2013 General Assembly.

The ten principles of the Code of Practice include:

1. Maintaining and continuously improving awareness and understanding of environmental stewardship, sustainability principles, and issues related to the field of practice.
2. If knowledge is not adequate to address environmental and sustainability issues, consult with others with the required expertise.
3. Global, regional, and local societal values should be incorporated to include local and community concerns, quality of life, and other social concerns related to environmental impact. Traditional and cultural values must be included.
4. Sustainability aspects should be incorporated at the earliest possible stage and employ applicable standards and criteria.
5. Costs and benefits of environmental protection, ecosystem components, climate change and extreme events, and sustainability should be incorporated in the economic viability of the work.
6. Environmental stewardship and sustainability planning should be over the life cycle for planning and management activities and efficient, sustainable solutions should be employed.
7. A balance between environmental, social, and economic factors should be achieved to contribute to healthy surroundings in the built and natural environment.
8. An open, timely, and transparent engagement process for both external and internal stakeholders should solicit input in and respond to economic, social, and environmental concerns.
9. Regulatory and legal requirements must be met and exceeded by applying best available, economically viable technologies and procedures.
10. In the cases where there are threats of serious or irreversible damage and scientific uncertainty, risk mitigation measures should be implemented in a timely fashion to minimize environmental degradation.

Engineers of all disciplines are involved in the development of technologies to improve life but must assure that impacts (social, economic, and environmental) are minimized. For example, Johnston (2016) indicated that process, civil, mechanical, electrical, instrumentation, and control engineers should work together with economists and scientists to ensure sustainable wastewater treatment and management solutions. Conferences such as STS Forum in Japan (held annually), Engineering for Sustainability (held in Denver, CO, February 18–19, 2016), and the 2015 Engineering Triennial Summit of the ICE/ASCE/

CSCE held in London, United Kingdom, are excellent examples of efforts to establishing collaborations between various societies. Climate change is also creating challenges. Engineering is essential in achieving the UN Sustainability Goals. Figure 8.8 shows some engineering actions for each of the selected goals according to the WFEO. Rating systems such as Envision or CEEQUAL can assist in the assessment of infrastructure project through goals and indicators and are a step in the right direction. Continual development of these and other tools is needed for other types of projects and processes.

An example of Envision ratings is the Platinum Award given to the New Champlain Bridge Corridor project in Montreal, Canada (Infrastructure Canada 2018). The bridge was designed to last 125 years. Some of the features of the project included:

- Design of the stormwater drainage system to take climate change into consideration
- Offset of GHG emissions by carbon credits
- Use of LED lights to reduce light pollution effects on migratory birds and energy requirements
- Recycling of 45% of the construction waste onsite and of the other 54% that was recycled, only 1% was sent to landfill
- Marshlands restoration and creation of new spawning habitats to offset loss of fish habitats, wetlands, and bird sanctuaries during construction of the bridge

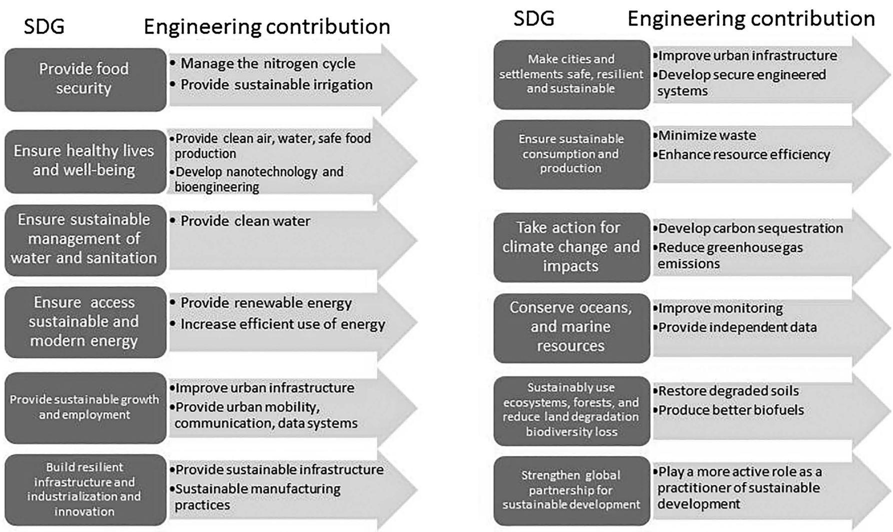


FIGURE 8.8
WFEO contributions toward selected UN Sustainable Development goals (WFEO 2015).

LCA can be complicated and difficult to implement. A life cycle approach, however, is essential. Life cycle sustainability assessment approaches are being developed which may be more appropriate than LCA due to inclusion of the social and economic aspects. Policies and incentives are needed to promote incorporation of sustainability in projects. Industries have made efforts to reduce wastes, emissions, energy uses, and report their progress through GRI standards.

8.4.3 Innovation for Sustainable Engineering

Bugliarello (2010) has identified various challenges for innovation for engineering, in the areas of materials, water and energy, IT, and bioengineering. Resources conservation and waste management are particularly relevant. Standards and regulations should not restrict innovation needed to advance sustainable practices. Nanotechnology, composite materials (especially with natural materials will improve material function and resource protection. The linkages of water and energy need to be addressed by considering both together not separately as is the current practice. Therefore, engineers and professional societies need position papers, metrics, and methodologies for guiding decisions, case studies, and data for enabling new ways of thinking in devising more effective water and wastewater treatment systems, reducing leakage for distribution systems, collection of energy from solar and wind power systems, and replacement of hydrocarbon fuels.

Materials that can be reused or recycled are highly desirable. Reuse and recycling of metals such as metals are essential. This includes aluminum, cobalt, copper, nickel, rare earth and platinum, iridium, gold and silver. Linear practices of waste management should be replaced by a more circular approach of disassembly, reuse, and recyclability. New products will need to be developed, in addition to new cans, car, airplane, and bicycle parts, rebar, etc. that is currently practiced. This requires thinking about the end of the life of a product from the beginning. This is a major challenge in addition to the complexity of the products. Metal sorting and separation are also part of the process. Research and development from the laboratory to pilot industrial scale are essential and supported by adequate funding.

Fenner and Ainger (2016) have indicated that water infrastructure should be monitored for water use and treatment. Harmful substances should be avoided and natural systems adopted such as wetlands and ponds for water management and restoring ecosystems. Water reuse in industry should be encouraged instead of water wasting. Indicators such as water footprinting can assist in promoting water resource conservation and smart water use.

Water is very connected to human activity with a high social and political nature; its availability is not equally distributed worldwide and can vary significantly seasonally and annually. Water use by industry can create significant public protests particularly when there is scarcity of water.

Water management is thus highly important and can drive innovation. As was recently addressed at the Civil Engineering Triennial Summit in London, climate change must be addressed now due to the increased risk of poverty, social inequity, terrorism, and conflict (Perks 2015).

The Innovation for Cool Earth Forum (2017) formulated a statement from the steering committee to further innovations toward net-zero emission of carbon dioxide in light of the Paris Agreement at the COP21. The statement is based on the forum of over 100 experts from many fields from 80 countries.

Some of the key points include:

- A peak of carbon dioxide emissions must be in the near future.
- Technological innovation is essential through zero emission technologies (renewables and nuclear energy), low carbon products, low carbon infrastructures, international cooperation, and financial and social innovation.
- Industrial sector participation in innovation and its diffusion.
- Utilization of a systems approach for diffusion of market-ready technologies (wind and solar power).

Perks et al. (2017) have provided some suggestions on what civil engineers can do. These include making sure existing infrastructure is working in an optimal manner. Leakage, for example, in water systems is a major problem due to water and energy wastage. Low cost, easy to operate, and socially acceptable solutions also must be identified instead of going with the usual practice. Consultation with stakeholders with "fresh eyes" through all stages of the project planning can bring new alternatives for consideration. Carbon neutral approaches for new infrastructures should be adopted. For example, as water pumping is a major user of energy, the use of gravity should be optimized. Future designs must be economically efficient to be affordable for the public and reduce poverty and must reduce and avoid energy consumption as much as possible to mitigate climate change. Key performance indicators are needed to measure progress.

8.5 Conclusions

There are presently many challenges for engineers. Education programs need to be expanded for engineers to include sustainable practices not as a special course but integrated into existing courses. Improved tools are needed. Envision and other tools are a good start but they are complex, hard to address over the life cycle of a project or process and many aspects are lacking, particularly regarding social equity and cultural issues. More partnerships are needed between social scientists, physical science, health and engineering professionals, education, governance and society. In summary, technology, education, regulation, and standards are all essential to promote and implement sustainable engineering practices. Interdisciplinary programs are necessary for training engineers in the circular economy.

Engineers need to work together and be more involved in decision-making at all stages of the project. They should become more involved in local or regional activities to assist in the decision-making. They need to consult with stakeholders for input regarding concerns and to adapt to local conditions. Even during the construction and/or operation phases, engineering should be able to address concerns and provide advice on the sustainability of a project. Research is needed to develop innovative solutions to this changing world under the influence of climate change and increasing uncertainty, deteriorating infrastructure, introduction of new chemicals into the environment, centralization and lock-in of technologies, and growing population to name a few. Engineers have an ethical requirement to rise to this challenge. They have indicated that they want to be involved in sustainable engineering practices. The role of engineers in sustainable development has been undervalued but it is critical. However, action is needed now.

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3

(Re)Think (Re)Design for Resilience

Nina-Marie Lister

CONTENTS

The summer of 2017 was one of the worst on record for flooding anywhere. From North America to Europe to South East Asia, record flood events were posted in coastal and inland areas alike. Torrential rainstorms, record-setting hurricanes, and surging Great Lakes levels combined to raise insurance premiums, public awareness, and political promises for flood protection and stormwater strategies. At a time of unprecedented global urbanization, both in scale and population, urban and urbanizing regions suffer disproportionate effects of flooding: in hard-surfaced cities, with more built form than vegetation, from rainfall to snowmelt, urban stormwater declines rapidly in quality and often has nowhere to flow but overland, bringing urban contaminants into swelling lakes, rising rivers, and subsiding coasts. In the transition to an urban world, the Anthropocene has ushered in a triple-threat: it's becoming clear that the profound social, technological, and built-form changes of urbanization are being exacerbated, tied inexorably through positive feedback to large-scale ecosystem and climate change. In short, the urban world is in urgent need of new modes of planning and design for resilience.

In the face of a changing climate, increasing vulnerability to extreme weather takes many forms. On December 21, 2013, for example, the city of Toronto and its metropolitan area of 5,000,000 inhabitants—along with a sizeable portion of southern Ontario and northern New York—experienced an unseasonably warm winter storm. The storm dropped more than 30 millimeters of freezing rain on the city. Temperatures hovered around freezing for almost 36 hours and then rapidly plummeted to −25°C and stayed there, locking the city under a blanket of ice for almost two weeks and leaving more than half a million residents in the frozen dark following the Winter Solstice. Under the weight of the ice, more than 20% of the city's 10,000,000 trees were felled, bringing down power lines and cables in the process and leaving thousands of homes without power, heat, or light through Christmas and the holiday season. With an estimated cost of CDN$106,000,000 to the city of Toronto alone in clean-up and emergency services, the eastern North American ice storm of 2013 is recorded as one of the worst natural disasters in Canadian history.[1] Yet, notably, this figure does not account for the loss of the green infrastructural value and the attendant ecosystem services of the loss of one-fifth of the city's mature tree canopy. The city will continue to suffer long-term related impacts of the ice storm through increased soil erosion, decreased flood protection, carbon sequestration, urban heat mitigation, and so on.

The ice storm, however, was not an isolated incident. In February 1998, a similar ice storm caused a massive power outage throughout Québec that lasted more than two weeks, affecting more than 50,000 homes in the middle of a deep freeze. The Red River floods of 1998 and 2012 crippled the cities of Winnipeg, Minneapolis, and St. Paul, while Alberta's Bow River flood of 2012 virtually shut down the city of Calgary and the Trans-Canada highway for more than a month. These are but a few of many recent, locally catastrophic storm events. The better-known "monster storms," such as Hurricane Katrina which devastated New Orleans in 2005, and Superstorm Sandy in 2011, which left half of midtown Manhattan without power for more than a week, are globally significant events. By virtue of their reach and effect in major urban centers, these storms have catalyzed a new wave of research into urban environmental planning, coastal defense, urban vulnerability, and related policy responses that link urbanism, planning, and ecology.

In addition to the economic, social, and environmental costs of such storms, there is growing recognition that these events pose significant challenges to the world's urbanizing areas and their largely outdated systems of governance and planning. Cities across the globe are facing the reality that the increasing magnitude and frequency of major storm events are evidence of human-induced global climate change, and with this reality has come a range of increasing challenges to our systems of survival, including a need for new design approaches to cope with ecological change and vulnerability.[2] Identified as a global threat by the *Intergovernmental Panel on Climate Change* (IPCC) and grounded in a wide range of policy-related research linked to long-term sustainability, climate change is now an accepted phenomenon for which adaptation strategies must be developed and implemented from municipal to national scales.[3]

Long-term environmental sustainability demands the capacity for resilience—the ability to recover from a disturbance, to accommodate change, and to function in a state of health. In this sense, sustainability refers to the inherent and dynamic balance between social-cultural, economic, and ecological domains of human behavior that is necessary for humankind's long-term surviving and thriving. Ann Dale has described this dynamic balance as a necessary act of reconciliation between personal, economic, and ecological imperatives that underlie the primordial natural and cultural capitals on Earth.[4] With this departure from conventional "sustainable development," Dale has set the responsibility for long-term sustainability squarely in the domain of human activity and appropriately removed it from the ultimately impossible realm of managing "the environment" as an object separate from human action.

A growing response to the increasing prevalence of major storm events has been the development of political rhetoric around the need for long-term sustainability and, specifically, resilience in the face of vulnerability. As a heuristic concept, resilience refers to the ability of an ecosystem to withstand and absorb change to prevailing environmental conditions. In an empirical sense, resilience is the amount of change or disruption an ecosystem can absorb, by which, following these change-inducing events, there is a return to a recognizable steady state in which the system retains most of its structures, functions, and feedbacks.[5] In both contexts, resilience is a well-established concept in ecological systems research, with a robust literature related to resource management, governance, and strategic planning. Yet, despite more than two decades of this research, the development of policy strategies and planning applications related to resilience is relatively recent. While there was a significant political call for resilience planning following Superstorm Sandy in 2011 and the ice storm of 2013, there remains a widespread lack of coordinated governance, established benchmarks, implemented policy applications, and few (if any) empirical measures of success related to climate change adaptation.[6] In this context, there has been little critical analysis of and reflection on the need to understand, unpack, and cultivate resilience beyond the rhetoric. In this essay, I argue that concomitant with the language of resilience is the need to develop nuanced, contextual, and critical analyses coupled with a scientific, evidence-based understanding of resilience; that is, we need an evidence-based approach that contributes to adaptive and ecologically responsive design in the face of complexity, uncertainty, and vulnerability. Put simply: What does a resilient world *look* like, how does it *behave*, and how do we plan and design for resilience in an urban world?

Why Resilience? Why Now?

The emergence of resilience as a rhetorical idea is tied not only to the emerging reality of climate change, but to an important and growing synergy between research and policy responses in the fields of ecology, landscape architecture, and urbanism—a synergy that is powerfully influenced by several remarkable and coincidental shifts since the turn of the second millennium. Most notable is the global population shift, in which our contemporary patterns of settlement are tending toward large-scale urbanization, a hallmark of the Anthropocene. The last century has been characterized by mass migration to ever-larger urban regions, resulting in the rise of the "megacity" and its attendant forms of suburbia, exurbia, and associated phenomena of the modern metropolitan landscape.[7] For most of the world's population, the city is fast becoming the singular landscape experience.[8]

In North America, and the United States in particular, this shift in urbanism has come, paradoxically, with a widespread decline in the quality and performance of the physical infrastructure of the city. The roads, bridges, tunnels, and sewers that were built during the late nineteenth and early twentieth centuries to service major urban centers are now aging and crumbling, in some cases, while both the political will and the public funds to rebuild this outdated but essential public infrastructure are disappearing. More significantly, these infrastructures continue to decay, and they are increasingly vulnerable to catastrophic failure in the face of more frequent and severe storm events, thus compounding the cost of their loss and the extent of impact (Figure 3.1).

The emergence of a new direction and emphasis in ecology represents another significant and concomitant shift with the change in urbanism and the reality of climate change. During the last few decades, the field of ecology has moved from a classical, reductionist concern with stability, certainty, predictability, and order, in favor of more contemporary understandings of dynamic, systemic change and the related phenomena of uncertainty, adaptability, and resilience. Increasingly, these concepts in ecological theory and complex systems research are found useful as heuristics for decision making generally and, with empirical evidence, for landscape design in particular.[9] This offers a powerful new disciplinary and practical space; one that is informed by ecological knowledge both as an applied science and as a construct for managing change within the context of sustainability. As a practice of planning *for and with* change, resilience is, in itself, a conceptual model for design.[10]

With this new ecological approach has come another important shift in creating the synergy necessary for resilience-thinking: the renaissance of landscape as both a discipline and praxis throughout the last two decades and its (re)integration with planning and architecture in both academic and applied professional domains. Landscape scholars have identified the rise of post-industrial urban landscapes coupled with a focus on indeterminacy and ecological processes as catalysts for the reemergence in landscape

FIGURE 3.1
Four views of a washed-out section of a major arterial roadway in Toronto after heavy rain and flooding of the Don River followed Hurricane Katrina, which was downgraded to a tropical storm when it hit Toronto on August 29, 2005. (Photo collage by Carmela Liggio and Nina-Marie Lister, 2005.)

theory and praxis.[11] Understood today as an interdisciplinary field, linking art, design, and the material science of ecology, landscape scholarship, and application now includes a renewed professional field of practice within the space of the city.[12]

Considered together in the era of climate change and vulnerability, these shifts in our collective understanding of urbanism, landscape, and ecology have created a powerful synergy for new approaches in planning and design to the contemporary metropolitan region. This synergy has been an important catalyst for the emergence of resilience as a rhetorical idea, but much work remains to be done to move toward evidence-based implementation of strategies, plans, and designs for resilience. The scale and impact of North American megastorms, such as Hurricane Katrina in 2005 and Superstorm Sandy in 2011 have been effective triggers for a new breed of policy and planning, initiatives in disaster preparedness in general, and flood management plans in particular. Conventional policy and planning approaches to natural disasters have long been rooted in the language of *resistance* and *control*, referencing coastal defense strategies, such as fortification, armoring, and "shoring up" by using brute-force engineering responses designed to do battle with natural forces.[13] By contrast, emerging approaches in design and planning reference the language of *resilience* and *adaptive management*, terms associated with elasticity and flexibility, leading to the use of hybrid engineering of constructed and ecological materials that adapt to dynamic conditions and natural forces.[14] Recent coastal management policies and flood management plans following the major storm events abound in this language of resilience, including New Orleans's *Water Management Strategy*, Louisiana's *Coastal Management Plan*, New York City's *Rebuild by Design* program, and Toronto's *Wet Weather Flow Master Plan*. These examples are notable as responses (reactive and proactive) to catalytic storm events and climate change, yet they remain, for the most part, speculative, untested, and unimplemented, relying on a language of resilience that is heuristic and conceptual rather than experiential, contextual, or scientifically derived.

The general concept of resilience has origins across at least four disciplines of research and application: psychology, disaster relief and military defense, engineering, and ecology. A scan of resilience policies reveals that the concept is widely and generally defined with reference to several of the original fields and is universally focused on the psychological trait of being flexible and adaptable. Examples are having the capacity to deal with pressure and the ability to "bounce back" to a known normal condition following periods of stress, maintaining well-being under stress, and being adaptable when faced with change or challenges.[15] The use of resilience in this generalized context, however, begs important operational questions of how much change is tolerable, which state of "normal" is desirable and achievable, and under what conditions is it possible to return to a known "normal" state. In policies that hinge on these broadly defined, psychosocial aspects of resilience, there is little or no explicit recognition that adaptation and flexibility may result in transformation and, thus, require the *transformative capacity* that is ultimately necessary at some scale in the face of radical, large-scale, and sudden systemic change. Using sea level as an example, if we accept that waters naturally rise and fall within a range of seasonal norms, we might be better off to embrace a gradient of acceptable "normal" conditions rather than a single static, and ultimately brittle, state that is unsustainable (Figure 3.2). A more critical and robust systems-oriented discussion of resilience will force all concerned to confront a difficult but

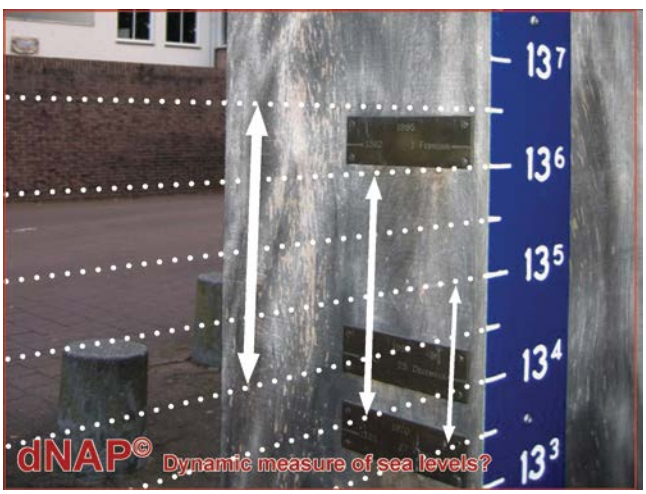

FIGURE 3.2
The Normaal Amsterdams Peil (NAP) is a measure used to gauge the rise in sea level and to establish national policies, laws, and regulations on the basis of a fixed, "normal" water level. In contrast, the Dynamic Normaal Amsterdams Peil or d(NAP), shown here, is a proposed measure of sea level for the Netherlands Delta Region that acknowledges dynamic water levels to address better changing hydrological regimes; for example, to reflect seasonal flooding. (Diagram courtesy of Kimberly Garza and Sarah Thomas, 2010.)

essential question: How much can a person, a community, or an ecosystem change before it becomes something unrecognizable and functions as an altogether different entity?[16] If resilience is to be a useful concept in application and, in particular, to inform design and planning strategies, it must ultimately instruct us *how* to change safely rather than how to resist change completely. Current policies and eventual design strategies will risk the potential power of resilience by emphasizing a misguided focus on "bouncing back" to a normal state that is, ultimately, impossible to sustain.

Unpacking Resilience

Before one can implement applied strategies and associated indicators for resilience in design and planning, it is useful and, arguably, necessary to unpack the history, theory, and conceptual development of resilience as it emerged in ecology. We can do so critically with reference to a well-established social-scientific literature derived principally from ecosystem ecology and, in particular, with research applications in natural resource management. Decades of research related to complex systems ecology, and thinking about and practice of social-ecological systems offers both broad heuristic and empirical contexts for the study and application of resilience. As such, both the construct and measures of resilience are important to embed, apply, and test within policies and designs for long-term sustainability. As an essential capacity for sustainability, applications of resilience are derived from research in complex systems ecology, first published by the American ecologist Howard T. Odum and later developed by the Canadian ecologist, Crawford Stanley ("Buzz") Holling.[17] Yet it should be noted that the foundations of resilience thinking were laid much earlier. Well before the language of complex systems was embraced within ecological science, the early twentieth century conservation movement was already concerned with the health of natural systems, which was conceptualized variously, from self-renewal to healing and balance, with implications for management practices. For example, Aldo Leopold used the concept of "land health" to refer to the land's capacity for self-renewal—essentially resilience—which he saw as threatened by and at odds with unchecked exploitation of land and resources for economic growth.[18] Similarly, Gifford Pinchot's perspectives on the need for cautious resource extraction, however utilitarian, gave rise to an early version of adaptive management to accommodate changes in nature and the landscape.[19] By the 1960s, with the birth of modern environmentalism, there were more urgent calls for caution. Notable among these was Rachel Carson's characterization of nature as resilient, changeable, and unpredictable: "… the fabric of life … on the one hand delicate and destructible, on the other miraculously tough and resilient, capable of striking back in unexpected ways."[20]

The late 1970s and early 1980s marked the beginning of a significant theoretical shift in the evolving discipline of ecology. In general, ecological research at all scales has moved toward a more organic model of open-endedness, indeterminacy, flexibility, adaptation, and resilience and away from a deterministic and predictive model of stability and control, based on engineering models for closed (usually mechanical) systems. Ecosystems are now understood to be open, self-organizing systems that are inherently diverse and complex and behave in ways that are, to some extent, unpredictable.

This shift, influenced by the early ecosystem analyses of the Odum brothers (Eugene P. and Howard T.), followed the rise in complexity science and the groundbreaking work of Ilya Prigogine, Ludwig von Bertalanffy, C. West Churchman, Peter Checkland, and other systems scholars throughout the latter half of the twentieth century. Ecological research came into its own discipline, distinct from biology and zoology, by focusing on large-scale and cross-scale (connected) functions and processes of an ecosystem. As an outgrowth of research in complex systems coupled with the emerging new discipline of landscape ecology and associated spatial analyses—made possible by new tools, such as high-resolution satellite imagery—ecosystem ecology led to multi-scaled, cross-disciplinary, and integrated approaches in land use planning. Beginning in the 1970s with F. Herbert Bormann's and Gene Likens' first ecosystem-based study of the Hubbard Brook watershed, long-term ecological research programs (known as LTERPs) became established, influencing, throughout the 1980s and 1990s, a growing recognition of the dynamic processes inherent and essential to living, layered landscapes, and the understanding of ecosystems as open, complex systems within which structure and function are interrelated and scale-dependent.[21]

The dynamic ecosystem model has been an important development in ecology and a significant departure from the conventional, linear model of ecosystems that dominated scholarly twentieth-century thought. Resilience is an important concept that emerged from this development. Defined by the process of ecological succession, the linear model held that ecosystems gradually and steadily succeed into stable climax states from which they will not routinely move unless disturbed by a force external to that system.[22] An old-growth forest is the typical example, in which a forest matures and then remains in that state permanently such that any disturbance from that state is considered an aberration. Yet we now know that not only is change built into these systems, but, in some cases, ecosystems are dependent on change for growth and renewal. For example, fire-dependent forests contain tree species that require the extreme heat of fire to release and disperse seeds and to facilitate a forest's renewal and, sometimes, a shift in the complement of a species following a major fire. The dynamic ecosystem model, based on long-term research in a variety of global contexts, asserts that all ecosystems go through recurring cycles with four common phases: rapid growth, conservation, release, and reorganization. Known as the adaptive cycle, or the Holling Figure Eight, this generalized pattern is a useful conceptual description of how ecosystems organize themselves over time and respond to change.[23] The adaptive cycle of every ecosystem is different and contextual; how each system behaves from one phase to the next depends on the scale, context, internal connections, flexibility, and resilience of that system (Figure 3.3).

Ecosystems are constantly evolving, often in ways that are discontinuous and uneven, with slow and fast changes at small and large scales. While some ecosystem states appear to be stable, stability is not equated in a mathematical sense but rather in a human-scale or time-limited perception of stasis. C. S. Holling pioneered this concept in application to resource management, in which he described ecosystems as "shifting steady-state mosaics," implying that stability is patchy and scale-dependent and is neither a constant nor a phenomenon that defines a whole system at any one point in time or space.[24] The key point is that ecosystems operate at many scales, some of which are loosely and others tightly connected, but all subject to change at different rates and under different conditions. An ecosystem we perceive as stable in a human lifetime may, at a longer scale, be ephemeral, and this realization has profound implications for how we choose to manage, plan, or design for that system (Figure 3.4).

There is an important connection between stability, change, and resilience—a property internal to any living system and a function of the unique adaptive cycle of that system. Resilience has both heuristic and empirical dimensions, arising from its origins in psychology, ecology, and engineering. As a heuristic or guiding concept, resilience refers to the *ability* of an ecosystem to withstand and absorb change to prevailing environmental conditions and, following these change events, to return to a recognizable steady state (or

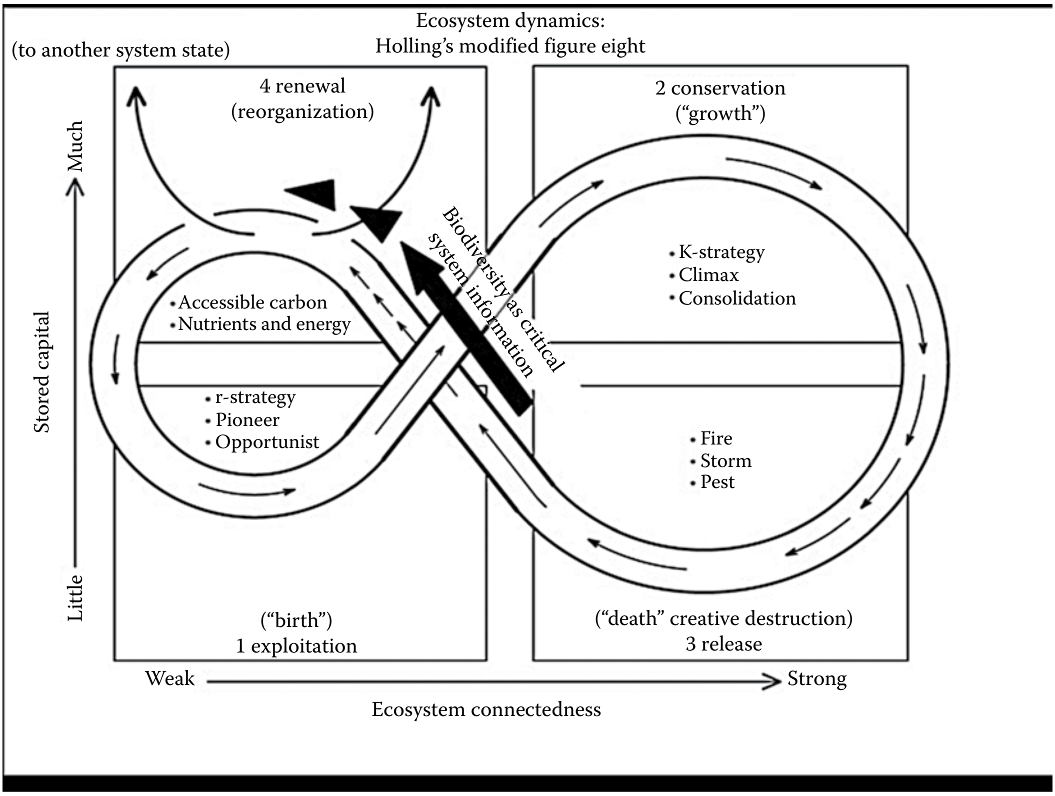

FIGURE 3.3
Ecosystem Dynamics and the Adaptive Cycle: Holling's Modified Figure Eight. Ecologist C. S. Holling's dynamic cycle of ecosystem development is the foundation of a complex systems perspective in ecology. (Diagram courtesy of Waltner-Toews, David, James J. Kay, and Nina-Marie E. Lister, eds. 2008. *The Ecosystem Approach: Complexity, Uncertainty, and Managing for Sustainability*. New York, NY: Columbia University Press. 97; modified from Holling, C. S. 2001. "Understanding the Complexity of Economic, Ecological, and Social Systems." *Ecosystems* 4(5): (August 2001): 390–405.)

a routinely cyclic set of states) in which the system retains most of its structures, functions, and feedbacks. As an empirical construct in engineering, resilience is the *rate* at which an ecosystem (usually at a small scale, with known variables) returns to a known and recognizable state, including its structures and functions, following change events. Such events, considered disturbances—which C. S. Holling strategically referred to in the vernacular as "surprises"—are usually part of normal ecosystem dynamics, yet they are also unpredictable, in that they cause sudden disruption to a system.[25] These can include, for example, forest fires, floods, pest outbreaks, and seasonal storm events.

The ability of a system to withstand sudden change at one scale assumes that the behavior of the system remains within a stable regime that contains this steady state in the first place. However, when an ecosystem suddenly shifts from one stable regime to another (in the reorganization phase, via a flip between system states or what is called a "regime shift"), a more specific assessment of ecosystem dynamics is needed. In this context, *ecological resilience* is a measure of the *amount of change* or disruption that is required to move a system from one state to another and, thus, to a different state of being maintained by a different set of functions and structures than the former (Figures 3.5 through 3.7).[26] Each of

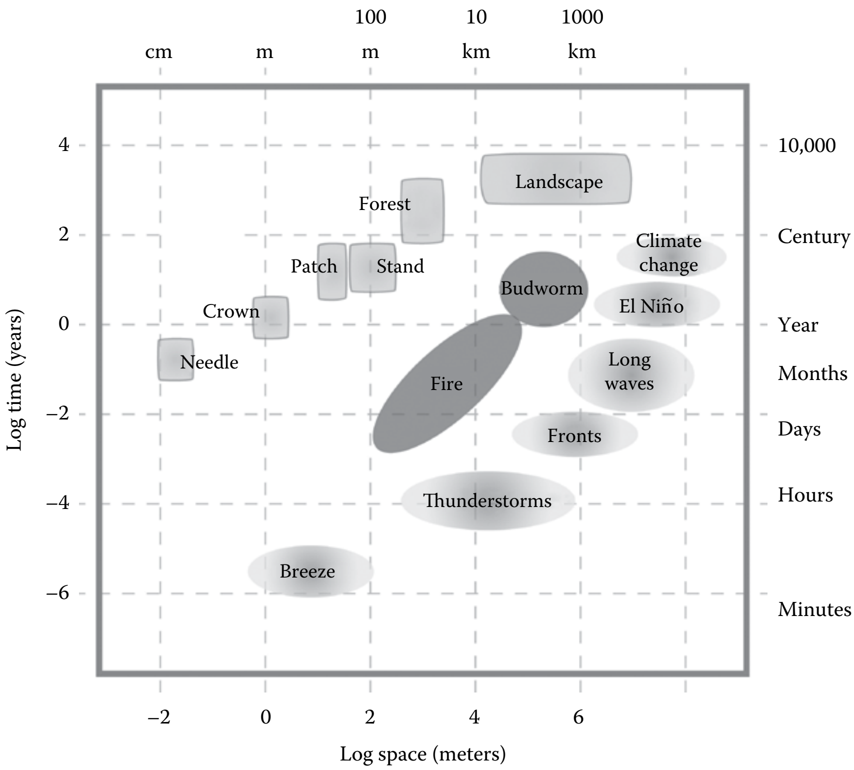

FIGURE 3.4
Ecosystem dynamics are observed here across multiple scales of time and space. (Redrawn by Marta Brocki and adapted from Holling, C. S. 2001. "Understanding the Complexity of Economic, Ecological, and Social Systems." *Ecosystems* 4(5): (August 2001): 390–405 [393].)

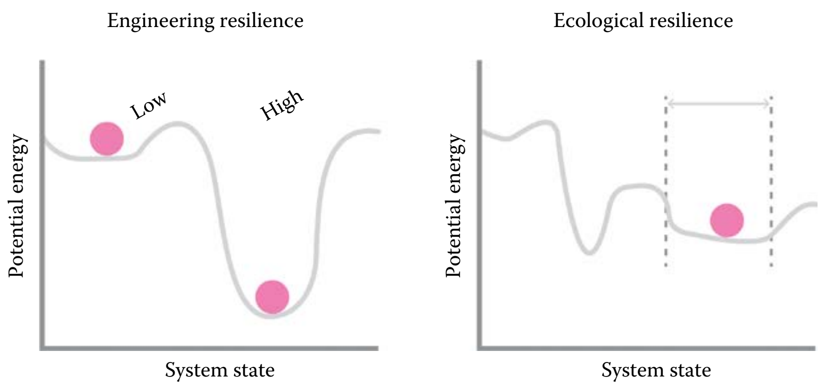

FIGURE 3.5
Shown here are two contrasting perspectives on resilience: (left) Engineering Resilience in closed systems (limited uncertainty and known variables) versus (right) Ecological Resilience in open systems (inherent uncertainty and infinite variables). (Redrawn by Nina-Marie Lister and Marta Brocki and adapted from Holling, C. S. 1996. "Engineering Resilience versus Ecological Resilience." In Schulze, P. C., ed. *Engineering within Ecological Constraints*. 31–44 [35]. Washington, DC: National Academy Press.)

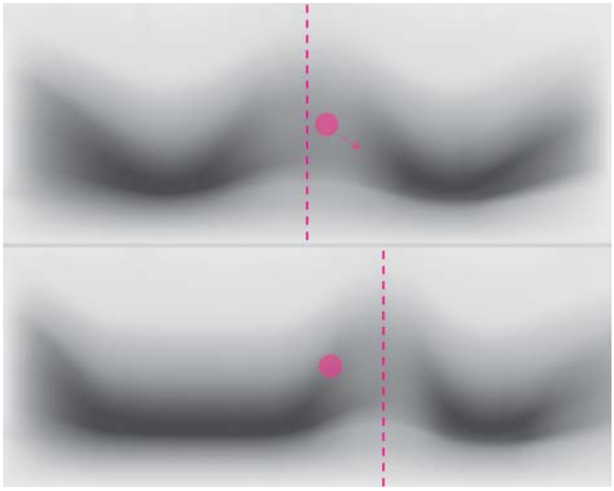

FIGURE 3.6
Resilience, seen here as a function of social-ecological system conditions, is described metaphorically as a ball in a changing basin. The basin represents a set of states that share similar functions, structures, and feedbacks. Though the location of the ball remains the same, changes in the surrounding conditions bring about a shift in state. (Redrawn by Marta Brocki and adapted from Walker, Brian, C. S. Holling, Stephen R. Carpenter, and Ann Kinzig. 2004. "Resilience, Adaptability and Transformability in Social–ecological Systems." *Ecology and Society* 9(2): (December 2004): 4. http://www.ecologyandsociety.org/vol9/iss2/art5.)

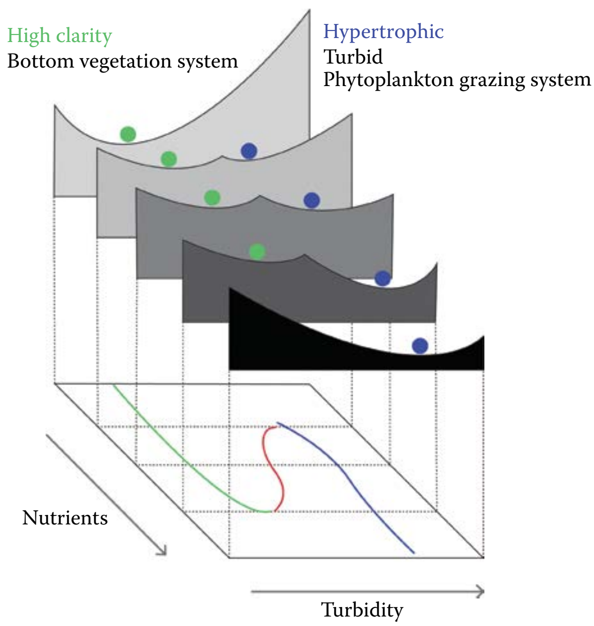

FIGURE 3.7
In this early schematic of a complex systems perspective in ecology, we visualize multiple states—all possible—in a freshwater ecosystem. (Courtesy of James J. Kay, as sketched in lectures from a course, "Systems Design Engineering," at the University of Waterloo, 1994, in which the author was a student. Redrawn by Marta Brocki and adapted from Kay, James J., and Eric Schneider. 1994. "Embracing Complexity: The Challenge of the Ecosystem Approach." *Alternatives Journal* 20(3):(July 1994): 32.)

these nuanced aspects of resilience is important. They underscore the social-cultural and economic challenges inherent in defining what "normal" conditions are and, in turn, how much change is acceptable at what scale.

It becomes critical to understand the ecological systems in which we live, and, given their inherent uncertainty, we ought to do so through a combination of ways of knowing: experiential, observational, and empirical. Indeed, if there are multiple possible states for any ecosystem, there can be no single "correct" state—only those we choose to encourage or discourage. Notably, these are not questions of science but of social, cultural, economic, and political dimensions—they are also questions of design and planning. The trajectory of research in resilience has been instrumental in exploring the paradoxes inherent within living systems—the tensions between stability and perturbation, constancy and change, predictability and unpredictability—and the implications of these for management, planning, and design of the land. Resilience, in short, as Brian Walker declares, "is largely about learning *how* to change in order not to *be* changed."[27]

From Rhetoric to Tactic: Toward Resilient Design

More recently, applied ecology has been focused on trying to understand what the ecosystem states are that we perceive to be stable, at what scales they operate, and how they are useful to us. It is important to recognize that stability can be positive or negative, just as change is neither universally good nor bad. Thus, while designers want to encourage a desirable stability (such as access to affordable food or a state of health for a majority of citizens), they also wish to avoid pathological stability (such as chronic unemployment, a state of war, or a dictatorship). This approach has significant implications for management, planning, and design, as it rests on the recognition that humans are not outsiders to any ecosystem but, rather, participants in its unfolding and agents of its design.

In this context, the sub-science of urban ecology developed during the 1990s has created a new niche for resilience.[28] Related practices of urban design, environmental planning, and landscape architecture have cross-pollinated in the service of design and planning for healthier cities within which connected vestiges of natural landscapes might thrive. The work of environmental scholars (such as William Cronin, Carolyn Merchant, and David Orr), together with the practice of landscape architects (such as Anne Whiston Spirn, Frederick R. Steiner, and James Corner) effectively brought nature into the embrace of the city, challenging the hierarchical dualism of humans versus nature.[29] The once-discrete concepts of "city" and "country" grew tangled and hybridized and the boundaries between the urban and the wild blurred. This blurring of boundaries, coupled with the contemporary ecological paradigm of nature as a complex, dynamic open system in which diversity is essential and uncertainty the norm, represented a significant break from ecological determinism and its slavish pursuit of perpetual stability underpinned by the illusion of the balance of nature.[30] The increasing hybridization of cultural and natural ecologies has created a powerful aperture for the development of resilience in thought and practice—and with it a new realm for design developed formatively through the interdisciplinary study of social-ecological systems science, in which coupled systems of humans *within* nature are the norm.[31]

What does design for resilience look like? What tactics do urban planners and designers need to engage in for attaining resilience? To activate such a model for design, one can summarize key principles of adaptive complex systems, generally, and of resilience, specifically.[32] First, change can be slow and fast, at multiple scales. This means that it is essential to look beyond one scale in both space and time and to use various tools to understand the ecological system. Slow variables are arguably more important to understand than fast ones, as they provide necessary stability from which to study change at a safe distance. Yet there can be no universal point of access or ideal vantage point. Mapping, describing, and analyzing the system from multiple perspectives, using different ways of knowing and with a diversity of tools, is critical. If uncertainty is irreducible and predictability is limited, then the role of the traditional expert is also limited—and the role of designer is more akin to a facilitator or curator.

Second, some connectedness or modularity across scales is important, and feedback loops should be both tight and loose. Resilient systems are not so tightly coupled that they can't survive a shock throughout the system that moves rapidly and destructively. For example, children need some limited exposure to viruses to develop immunities but at not too large a scale of impact so as to endanger long-term health. In the same way, design strategies for resilience must consider novelty and redundancy in terms of structures and functions. A useful example is a trail system in a park, which is somewhat connected using a hierarchy of paths that is legible and efficient and yet not so tightly connected that it compromises habitat, folds in on itself, or prohibits spontaneous exploration.

Third, even as there are multiple states in which an ecosystem can function, there is no single correct state. It is important to determine where, in the adaptive cycle, the system of interest is, such that decision makers and designers can learn patterns and anticipate change (if not predict it). Eventually, perceived stability in any phase will end, and the system will move to a new phase in its adaptive cycle. A non-linear approach to design that encompasses oscillating or changing states within various phases of a system's development will help facilitate change. For example, it may be desirable to design for seasonally flooded landscapes or along a gradient of water that changes rapidly in a short period of time.

Finally, resilient systems are defined by diversity and by inherent but irreducible uncertainty. Successful strategies for resilient design should use a diversity of tactics through *in situ* experimental and ecologically responsive approaches that are safe-to-fail, while avoiding those erroneously assumed to be fail-safe.[33] This distinction is important, for conventional engineering relies on prediction and certainty to assume an idealized condition of fail-safe design. Yet this is impossible under dynamic conditions of ecological and social complexity in which predictability is limited at best to one scale of focus. Even knowing one scale exhaustively and managing for it specifically and exclusively may compromise a system's overall function and resilience. The reductionist caveat of "scaling up," using knowledge gained at one scale and applying it to the whole system, cannot work in complex systems in which scales are nested. Design strategies that support and facilitate resilience should, for example, model its attributes, using living infrastructures that mimic ecological structures and their functions, and to design them to be tested and monitored, from which learning and adaptation to changing conditions are built into the design. When design experiments fail, they should fail safely, at a scale small enough not to compromise long-term health.

These and other emerging approaches to design for resilience tend to reflect the characteristics of the theoretical paradigm shifts that have laid its foundation. They are often interdisciplinary, integrating architecture, engineering, and ecology, specifically, and art and science, broadly. They cross-pollinate freely across scales and hybridize in surprisingly novel ways.[34] The growing use of living "blue" and "green" infrastructures[35] to soften seawalls, anchor soils, provide rooftop habitats, clean stormwater, soak and hold floodwater, and move animals safely across highways[36] are a collective and optimistic testament to the emergence of a new breed of urban and landscape designers whose creative work mimics, models, and manifests the living systems that inspire and sustain us. Yet activating resilience requires a subtle and careful approach to design: one that is contextual, legible, nuanced, and responsive, one that is small in scale but large in cumulative impact. In (re)thinking design, and in (re)designing for change with this sensibility, we have begun to cultivate a culture of resilience and the adaptive, transformative capacity for long-term sustainability—thriving beyond merely surviving—with change in the urbanizing landscapes that now define us.

Acknowledgments

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Endnotes

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than 8,000,000 residents, yet today there are more than 20 megalopoli, most in Asia. See Chandler, Tetrius. 1987. *Four Thousand Years of Urban Growth: An Historical Census*. Lewiston, NY: St. David's University Press; and Yvonne Rydin and Karolina Kendall-Bush. 2009. *Megalopolises and Sustainability*. London, UK: University College London Environment Institute. http://www.ucl.ac.uk/btg/downloads/Megalopolises_and_Sustainability_Report.pdf.

8. According to the World Health Organization, the percentage of people living in cities is expected to increase from less than 40% in 1990 to 70% in 2050. See "Global Health Observatory: Urban Population Growth," World Health Organization, available at http://www.who.int/gho/urban_health/situation_trends/urban_population_growth_text/en/.
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14. See, for example, Lister, Nina-Marie. 2009. "*Water/Front*," *Places*. Design Observer Online. http://places.designobserver.com/feature/water-front/10227/.
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16. Brian Walker, Chair of the Resilience Alliance and research fellow at the Stockholm Resilience Centre, provides an excellent overview of this aspect of resilience in https://www.project-syndicate.org/commentary/what-is-resilience-by-brian-walker (accessed July 5, 2013).
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2

Sustainable Development and Climate Change

2.1 The Concept and Objectives of Sustainable Development

By analysing the historical development of the concept of sustainable development, the stages of the historical development of the relationship between humanity and the natural environment are often distinguished. The first stage covers the period before the Industrial Revolution and is often treated as a period of human life in harmony with nature by scientists. In fact, at this stage in the evolution of the relationship between the individual and nature, nature dictated its conditions to the human, while the human became awed by nature, often deified it, and tried to accommodate to it as much as possible. In this case, Pagan traditions – sacred groves, sacred rivers, and lakes – well reflect the essence of this approach.

The second stage in the historical dimension of human–nature relations is associated with rapid advances in science and technology, which have led to the formation of a worldview of the conquest of nature, focusing on the fact that humans can conquer nature by changing it according to their own needs and discretion. Constantly accelerating economic development and increasing production volumes have enhanced the growth of the population and increased demand for natural resources, while the increasing use of natural resources has enlarged environmental pollution, which from local or regional has grown to the global level. At this stage, the environment is seen by humans as the building material for creating a more perfect, better world; thus, the humanistic paradigm is displaced by the technocratic paradigm. The core of this stage is the formation of a long-lasting confrontation between the human and nature, which has allowed humans to feel independent from the surrounding nature.

The third stage, explaining the relationship between the human and nature, is often referred to as the stage of human–nature harmonisation with the main aim of reducing the negative effects of economic development on the environment. It emerged by questioning whether the humankind is indeed on the path to full advancement, whether the social and natural environment will be continually improved, and whether material prosperity, regardless of exploitable natural resources, will be achieved without harming the society and the surrounding environment. Precisely in the third stage, environmental problems have been viewed not as negative changes in nature, but as social problems caused by people in their daily lives (Čiegis 2004). In order to solve these problems, it is necessary to use not only the latest tools of scientific and technical progress, but also the inclinations of society, their culture of consumption, their habits, and attitudes established over time.

As a result of these historical stages of the relationship between humanity and the natural environment, the necessity of assessing the responsibility of humanity for their actions arose, as it became evident that further uncontrolled expansion of the technosphere threatens to completely destroy the vital elements. At the same time, not the question "Can the biosphere adapt to change?" but another one arose: "Can the biosphere adapt to change so quickly?" The question of speed arose because the pace of human development surpassed all expectations. At the same time, a new approach to economic growth formed and the understanding and meaning of these concepts began to change, as it became clear that the growth process could be destructive (Čiegis 2004, 2006).

Many postulates on harmony development between humans and environment, in particular the living part of it (flora, fauna), are also easy to find in various religions, especially Buddhism, where a human is considered an integral part of nature. On the other hand, we have to admit that Christianity, which has elevated the human as the perfect and God-like creature above the living nature, is far less favourable to the harmonious relationship between humans and nature. Thus, it is no coincidence that as the civilisation evolves, first and foremost, the deep problems of human–environment relations emerge namely in Christian countries.

The discussions on the relationship between economic growth and the environment are long-standing, complex, and fundamentally unresolvable to this day. The origins of these disputes, though linked to Adam Smith's work An Inquiry into the Nature and Causes of the Wealth of Nations, published in 1776, are often traced back to the ideas of Thomas Robert Malthus outlined in his famous work An Essay on the Principle of Population As It Affects the Future Improvement of Society. The ideas of Malthus were in stark contrast with the ideas about the need to ensure a continuous process of economic growth expressed by Adam Smith in The Wealth of Nations. Thomas Robert Malthus, who developed his own population theory, stating that population dynamics are limited by declining efficiency of the resources, claimed that the population grows in geometric progression, while means of subsistence only in arithmetic progression at best. Thomas Malthus was right in speculating that the population will grow geometrically but was wrong in claiming that food production will increase arithmetically, because he did not foresee humanity's ability to geometrically improve the technology used in agriculture, and did not realise that the economic law of diminishing results is valid only under the immutable status of technologies. Consequently, although Thomas Malthus presented a strong model, its simplicity limited its relevance to political decision-making (Čiegis 2004).

It is worth noting that the problems (overpopulation) raised by Thomas Malthus, Karl Marx's teachings on misallocation, and John Maynard Keynes's doctrine of obligatory labour, all had one common solution to their problems – economic growth. Growth was the general response to all problems. Thus, this expansionist view of the world – a panacea for unmanageable and unbridled economic growth – is also one of the threats to the development of the modern world. Talks over environmentally balanced development to eliminate and prevent (current) consequences of unrestricted economic growth began only in 1983.

The modern version of the neo-Malthus theory was studied by Ehrlich (1989) and Hardin (1968, 1993). They extended pessimistic ideas and stated that uncontrolled population growth would undermine life-sustaining functions and lead to environmental, social, and economic disasters. The identification of a set of such problems can be seen as the beginning of the formalisation of the sustainable development process.

Subsequent ideas focusing on the interpretation of the optimal relationship between humanity and resources were explored in Daly's works Toward a Steady-State Economy (Daly 1980) and Steady-State Economics (Daly 1991). Other classical economists, such as David Ricardo and James Mill, also understood the limitations of natural resources available to humanity and their impact on the scale of economic activity and, therefore, considered long–term economic growth difficult to achieve. Land constraints caused the main concern for resource scarcity. David Ricardo predicted that with the growth of population, land shortages would increase and society would be forced to cultivate increasingly poorer land and, as a result, the price of agricultural products would rise. However, David Ricardo believed that human resources and technological development would help to delay the period when humanity's needs would exceed the possibilities of natural resources (Čiegis 2006).

For a long time, in the discussions about the relationship between economic growth and the environment, a pessimistic attitude prevailed, which is best reflected in the famous report The Limits to Growth written to the Club of Rome by Donella Meadows et al. (1972). The report aimed to clarify the limits of production expansion and population growth, while the starting point was the frightening exponential growth of the population and the economy. The conclusions reached by the scientists were disappointing: the contradictions between nature's limitations and the extremely rapid growth pace of its use, the increasing environmental pollution and the rapid population growth in the mid-21st century could lead to a global ecological crisis. The Limits to Growth and the subsequent projects developed on the initiative of the Club of Rome, such as Beyond the Age of Waste, Goals for Mankind, formed a new mentality and brought the need to ensure global equilibrium to the forefront (Čiegis 2006).

Around 1935, when, through the millennia, the mankind had already been well adapted to the local ecological systems, the English scientist Arthur Tansley introduced the concept of “ecosystem” as a scientific category, which was defined as a dynamic complex of living organisms (plants, animals, and micro-organisms) and non-living environment (soil, water, and air). While the scale of humanity’s economic growth was relatively small, it was possible to ignore the fact that the human economy was involved and dependent on the ecosystems of our planet (Čiegis 2004). However, in the long run, there was no area of nature left untouched by a human and without a proper assessment of the ecosystem’s condition for a long time, humankind faced ecological problems.

In 1969, at the session of the UN Council, global crisis was brought up since, through continued economic growth and the waste of natural resources at excessively fast rates, it equally threatened both developed and developing countries.

In 1972, at the United Nations Conference on the Human Environment in Stockholm, the connection between economic development and environmental impact was recognised, and the term “ecological development” was proposed. In the Declaration, adopted during the Conference, the key principles were expressed, which must be followed by states in rationally harmonising the relations between development and environment. The first principle of the Declaration proclaimed that “Man has the fundamental right to freedom, equality and adequate conditions of life”. The other articles of the document outlined the policy principles and guidelines on rational use and protection of renewable and non-renewable natural resources, relations of economic development and environment as well as scientific and technical progress. The Conference also developed a comprehensive plan of measures with 109 recommendations that covered the most pressing questions of the environmental benefits of that period (Report of the United Nations Conference on the Human Environment 1972).

This concept of global resource management gave Western countries hope for a comprehensive solution to the problems of environmental pollution. However, developing countries made it clear that their objectives and development policies (or, more specifically, economic growth) of that period were a much higher priority than environmental concerns. And yet, notwithstanding all the contradictions that had arisen among countries of different development levels, for the first time, environmental issues were reviewed in a global context, and the idea of the necessity to link ecological problems and their solution to economic and social development was expressed at the Stockholm Conference (Čiegis 2006).

The origins of the current concept of sustainable development date back to 1980, when a vital document – World Conservation Strategy – was published on behalf of the International Union for Conservation of Nature (IUCN), the United Nations Environment Programme, and the World Wildlife Fund. This document completely abandoned the opposition between nature conservation and economic development, postulated in the concept of human survival, and explicitly declared that development and protection were not contradictory, while the rational use of natural resources was an integral part of social development and nature protection. This was the path towards the widely recognised concept of sustainable development (World Conservation Strategy 1980).

As the concept of sustainability was being developed, a significant role was played by the 1986 Ottawa Conference on Conservation and Development organised by IUCN and held to assess the World Conservation Strategy and set out guidelines for its review; moreover, justice and social legitimacy were considered such significant aspects that even the phrase "sustainable and equitable development" was used in the Conference. In the documents of the Conference, the need for a radical change of the old development model is indicated, noting that we need an alternative society, another type of development associated with structural change (Čiegis 2006).

In 1987, the sustainable development philosophy was formalised with the report Our Common Future by the UN World Commission on Environment and Development that had an infinitely noble goal to make the world prosper and be generous to all (Our Common Future 1987). In this report, for the first time in the history of the evolution of the concept of sustainable development, a qualitatively new notion of economic growth has been defined: it is rapid and, at the same time, socially and environmentally sustainable (responsible) economic growth. From this point on, it was agreed that sustainable development encompasses three dimensions – economic, social, and environmental – and that all economic growth shall be achieved by considering the remaining two aspects of economic growth (social and environmental).

Thus far, sustainable development issues have been fundamental and insignificant in the international climate change policy: they have been fundamental in the sense that the reduction of greenhouse gas (GHG) emissions and economic development have often been seen as contradictory. Over the years, policymakers have repeatedly expressed their concerns that ambitious climate policies are limiting development, reducing the number of jobs, damaging the industry, and lowering the standard of living.

At the same time, the link between climate change and sustainable development has hardly been studied. In climate policy, the risk of "carbon leakage" is discussed in detail: this ambitious climate policy can stimulate the relocation of industrial production to other countries; however, the discussions have traditionally focused on calculating GHG emissions and discounting the wider social and economic impacts of climate change actions such as benefits and costs (Ürge-Vorsatz et al. 2014).

Policymakers often do not take climate change into account when planning their economic development. This is clearly illustrated by the current state of the energy sector where coal combustion is still used, and the state of the transport sector, which is reflected by the transport infrastructure that does not consider climate change. This is due to the fact that different ministries have different approaches and due to a lack of policy coherence. The situation is expected to change and improve significantly with the implementation of two milestones: The Paris Agreement and the 2030 Agenda.

The Paris Agreement is the first global agreement on sustainable development based on data assessment and analysis. The legally binding provisions for information flows are aimed at a civilisational transformation and transition of individuals from rural poverty to the urban middle class, while maintaining a global level of well-being and not crossing ecological boundaries.

Key elements of the Paris Agreement:

- Long-term target: Governments have agreed to ensure that the global average temperature increase is well below 2°C compared to pre-industrial temperature while making efforts to keep it below 1.5°C.
- Actions: Before and during the Paris Conference, countries presented comprehensive national climate action plans that aim to reduce their emissions.
- Ambition: Governments have agreed to report on their actions every 5 years, in this way setting even more ambitious targets.
- Transparency: They also agreed to inform each other and the public of their progress in achieving their goals to ensure transparency and observation.
- Solidarity: The European Union and other developed countries will continue to provide financing to developing countries in order to fight climate change by helping them to reduce emissions and increase their resilience to the effects of climate change.

In 2015, the General Assembly of the United Nations adopted the resolution Transforming our World: the 2030 Agenda for Sustainable Development.

2.1.1 Sustainable Development Goals

The resolution Transforming our World: The 2030 Agenda for Sustainable Development signed by the President of the Republic of Lithuania and heads of other 192 countries at the General Assembly of the United Nations officially came into force at the beginning of 2016, introducing Sustainable Development Goals to governmental authorities. This resolution is the result of thorough and comprehensive 3-year negotiations that involved international, national, and regional players from intergovernmental, governmental, and regional institutions, public and private sectors, and the civil society. These goals are important at both global and national levels and encompass both global and national actions with the aim of making our planet more sustainable. The 2030 Agenda is much more ambitious than the Millennium Development Goals and covers a bigger number of issues, and it shall be implemented by developing and developed countries. In the Agenda, 17 Sustainable Development Goals, based on the achievements of the Millennium Development Goals, and including new ones – climate change, economic inequality, innovations, sustainable consumption, peace and justice as well as other priorities – are established. In order to accomplish these goals, a system of 99 indicators has been established, which may fundamentally differ from the system of indicators for assessing sustainable development formed by the United Nations.

The Sustainable Development Goals set out in the Agenda:

Goal 1: End poverty in all its forms everywhere. This goal is ambitious, but it is believed to be possible. In 2000, the world had committed to half the number of people living in absolute poverty by 2015, and this goal was achieved. However, more than 800 million people around the world still live on less than USD 1.25 a day – that corresponds to the total number of Europeans living in extreme poverty. The time to completely eradicate all forms of poverty is now.

Goal 2: End hunger, ensure food security and improved nutrition, promote sustainable agriculture. Malnutrition causes almost half (45%) of deaths of children before reaching age five; that is up to 3.1 million children each year. Across the developing world, 66 million primary school-age children attend classes hungry with 23 million of them being in Africa alone. However, in the past 20 years, hunger has dropped by almost half. Many countries that have suffered hunger and poverty in the past are able to satisfy the nutritional needs of the most vulnerable people. This is an incredible achievement. The time to end poverty and hunger as well as to take care of a healthy diet of the population is now. This requires the support for the development of sustainable agriculture and promotion of small and medium farmers, who supply high-quality food for the locals.

Goal 3: Ensure healthy lives and promote well-being for all at all ages. Everybody knows that the most important thing in the life of all individuals is their health. It has the greatest impact on our quality of life and on what we create and what we can create. Therefore, the realisation of this goal will ensure that every individual has access to the healthcare system of good quality, effective medication, and vaccines. By the time the already mentioned goal was set, children and maternal mortality rate had plunged by more than half in 25 years, which means that this goal can be achieved. However, some problems still need to be tackled such as AIDS, which is the leading cause of death among adolescents in sub-Saharan Africa.

Goal 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. Poverty, armed conflicts, and other extreme situations have forced many children around the world to stop going to school. There are many regions around the globe where children do not even have access to primary education and many vulnerable households where children do not have the opportunity to go to school. However, since the year 2000, the significant progress towards primary education for all children worldwide has been made: the overall education level in developing regions has reached 91%.

Goal 5: Achieve gender equality and empower all women and girls. The progress that the world has made in the area of gender equality is commendable, but not all problems have been solved. Girls and women still face discrimination not only in public life but also in the labour market. Significant pay gaps still exist today as well as many unpaid "female jobs", e.g., childcare and work at home. The examples of women discrimination in public decision-making and political participation have also been observed.

Goal 6: Ensure availability and sustainable management of water and sanitation for all. Every individual on Earth should have access to drinking water. This is the goal of the year 2030. Although many people take clean drinking water and sanitation for granted, it should be kept in mind that water scarcity directly affects more than 40% of the world's population. To put it in other words, more than 3 billion people suffer from the lack of drinking water and unsanitary conditions in which they have to live. It is believed that this number is going to soar on account of climate change. If we continue along this path we are on now and not make any changes, by the year 2050 at least one in four people will experience the shortage of drinking water. The new path is more focused on international cooperation in protecting swamps and rivers as well as sharing water treatment technologies that lead to the goal accomplishment.

Goal 7: Ensure access to affordable, reliable, sustainable, and modern energy for all. From 1990 to 2010, the number of people with access to electricity increased by 1.7 billion. This is a gratifying achievement. However, as the world's population continues to grow, more and more people will need cheap electricity to light up their homes and streets, use their phones and computers, and work every day. We generate energy by burning fossil fuels and, thus, increasing GHG emissions, which has a direct impact on climate change and causes many problems in every part of the world. Hence, we have to become a more energy-efficient society and make larger investments into more clean energy sources, e.g. solar or wind energy. By these means, we will meet electricity demand and protect the environment.

Goal 8: Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all. A significant part of economic growth is a sufficient salary, which ensures the quality of life. The good news is that the middle class is growing all over the world: it has almost tripled in developing countries over the past 25 years. Today, however, job growth is lagging behind the growing workforce. Therefore, entrepreneurship must be encouraged to ensure new workplaces by eliminating forced labour, child exploitation, and human trafficking.

Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialisation, and foster innovation. Technological progress helps to deal with great global challenges, e.g. create jobs and use electricity more efficiently. For instance, the world is becoming more and more interrelated and thriving because of the common interest that results from the globalisation processes. Opportunities to take advantage of knowledge management, wisdom, and benefits of the virtual world are increasing. However, 4 billion people, most of whom are from developing countries, do not have access to the Internet. Narrowing the digital divide, promoting sustainable industrial development, and investing in research and innovation are important ways to promote sustainable development.

Goal 10: Reduce inequality within and among countries. We must approve the policy that creates an opportunity for everyone, regardless of who they are or where they come from. Income inequality is a global issue that requires global solutions. This implies that the following steps need to be taken: improving regulation of financial markets and institutions, sending official development assistance where it is most needed, and helping people to migrate safely so that they can take advantage of the opportunities of the global world. Together we can now change the direction of inequality from the old history.

Goal 11: Make cities and human settlements inclusive, safe, resilient, and sustainable. Currently, more than half of the world's population does live in cities, and this number will account for about two-thirds of humanity by the year 2050. Cities are getting bigger. In 1990, ten "big cities" with a population of 10 million or more existed in the world; in 2014, 28 million cities with 453 million people were counted. Many people prefer living in cities due to their cultural centres that exist there; however, at the same time, they are gradually becoming centres of poverty. In order to make cities sustainable for all, we can create good, affordable public housing. We can invest in public transport, create green spaces, and get a wider range of people involved in urban planning. By doing so, we can keep things that we like as they are and change the ones that we disfavour or that are just harmful.

Goal 12: Ensure sustainable consumption and production patterns. The level of consumption of some people is particularly high while others consume very little. There is a considerable difference or so-called consumption inequality that manifests itself in a very small proportion of the population, whose consumption is particularly high, and in the majority of the population that consume very little, often even too little to meet their essential needs. Our aspiration should be the world in which everyone has access to the things they need in order to survive and prosper. The consumption level should be maintained in a way that preserves natural resources so that our children would be able to use them as well as their children. The most onerous part is how to achieve this goal. We can manage our natural resources more efficiently and handle waste correctly.

Goal 13: Take urgent action to combat climate change and its impacts. Every country in the world is facing drastic consequences of climate change. Direct loss due to earthquakes, tsunamis, tropical cyclones, and floods is estimated at hundreds of billions of dollars per year. We can reduce the damage of property and losses of life by helping more vulnerable regions, e.g. inland countries and island countries which have to become more resistant to the consequences of climate change. By taking into account political will and technological measures, it is still possible to limit the increase of average temperature on a global scale to 2°C compared with the pre-industrial level. Thus, the catastrophic consequences of climate change may be avoided.

Goal 14: Conserve and sustainably use the oceans, seas, and marine resources for sustainable development. Ocean temperatures, chemistry, and their life forms are incredibly important components of our planet. Survival of over 3 billion people depends on the diversity of seas and coasts. Oceans absorb about 30% of carbon dioxide emitted by humans during manufacturing processes, but emissions have been going up recently, and consequently, oceans become more acidic – since the beginning of the Industrial Revolution, the acidity has increased by 26%. According to the latest estimates, on average 13,000 pieces of plastic litter float on every square kilometre of the ocean.

Goal 15: Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation, and halt biodiversity loss. Vegetable oil constitutes 80% of total human nutrition. Forests, which cover 30% of the world's land surface, help to keep air and water clean. However, earth and life on it are in danger. Arable land is disappearing 30–35 times faster than in the past. Deserts are expanding. Animal breeds are becoming extinct. This Sustainable Development Goal is aimed at preserving and restoring dryland ecosystems by 2030.

Goal 16: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable, and inclusive institutions at all levels. No country develops without peace and justice in it, without human rights or government based on the rule of law. Yet, in some parts of the world, relative peace and justice dominate, and individual countries suffer from armed conflicts, crimes, torture, and exploitation that hinder their development. Peace and justice are the goals for all the world's countries. The aim of this Sustainable Development Goal is to reduce all forms of violence and to suggest governments and communities finding long-term solutions to the conflicts and insecurities. This means strengthening the rule of law, reducing the illegal flow of arms trafficking, and involving developing countries in institutions of global governance.

Goal 17: Strengthen the means of implementation and revitalise the Global Partnership for Sustainable Development. Today, more than ever before, the world is interrelated due to possibly accessible new information technologies, travels, and global institutions. There is a growing consensus that we need to work together in order to halt the consequences of climate change.

767 million people on the planet still live on less than USD 1.90 a day, whereas 793 million people face a shortage of food and drinking water on

a daily basis (United Nations 2017). Our planet needs a more resolute policy to reduce maternal mortality, achieve sustainable energy goals and larger investments in sustainable infrastructure as well as ensure the rights of every child to quality education. It is estimated that if all children, eligible for learning, graduates from high school by 2030, per capita income will rise by 75% till the year 2050, we may win the fight against poverty in a decade (United Nations 2017).

Almost all the Sustainable Development Goals are related to climate change to some extent. This issue has even been marked out by a separate point, namely, Goal 13. Measures to halt climate change are envisaged and, in the cases, when it is impossible to do so, to apply effective adaptation measures.

However, at first glance, in the Sustainable Development Goals, very little attention is paid to the element of culture and the role of culture while forming a sustainable and smart society. The cultural issue is closely related to the issue of climate change, and this possibly new component of sustainable development can be used effectively to achieve the Sustainable Development Goals that are, as already mentioned, either literary or figuratively related to climate change.

Modern society is transforming into a new, sustainable, and environmentally friendly society with the aim of providing humanity opportunities to build safer, healthier, and richer world where all the people have access to constant teaching and learning, new knowledge, and values and the need to know, understand, and make meaningful and responsible actions (Chakori 2017). None of the Sustainable Development Goals is directly culture oriented, i.e. definitions do not use the concept of culture directly. Despite this, it is worth paying attention to several aspects. The fourth Sustainable Development Goal aims to ensure all-encompassing and equal quality education, which can be implemented by acquiring new and relevant knowledge that would help to promote sustainable development. In order to achieve this goal, already existing and possible measurements that encourage citizenship in society and accessibility to cultural diversity by assessing the contribution of culture to sustainable development shall be used.

Another Sustainable Development Goal, which may promote sustainable, inclusive, and sustained economic growth, is oriented towards a comprehensive development policy of the countries with the goal of creating and forming a sustainable economy, which is possible only by supporting productive activities, using innovations as well as personal or group creativity and other related activities.

Goals 9 and 10 refer to the implementation of a concept of sustainable tourism. The sustainable tourism stimulates resilient infrastructure building, promotes inclusive and sustainable industrialisation, and increases opportunities for innovations and their successful implementation not only in large cities as it provides the evaluation of local elements of culture in creating necessary monitoring tools.

2.1.2 Integration of Culture to Achieve the Sustainable Development Goals

Cultural participation has a significant impact on people's quality of life: it contributes to their well-being and promotes a sense of belonging to a society.

The eleventh Sustainable Development Goal, the main objective of which is inclusive, safe, and sustainable cities and settlements, is of particular importance culturally. The achievement of this goal can be realised by the implementation of programmes and strategies that directly oblige countries to protect cultural and natural heritage.

Consequently, cultural aspects play a significant role in achieving the Sustainable Development Goals. Table 2.1 shows links between the Sustainable Development Goals and culture.

The cultural aspect of sustainability creates strong relations and is compatible with the other three dimensions of sustainable development. The conceptualisation of culture as the fourth component of the sustainable development, along with the ecological, social, and economic components, is based on a well-established and simple approach. Such an approach has its own dangers because culture can be viewed in a rather limited way as an artistic and cultural-creative sector (Hawkes 2001). This narrows down the definition of culture. It is important to note that this concept allows culture to be understood both qualitatively and quantitatively. Nevertheless, the role of the fourth component offers many opportunities. In this way, culture can be connected to the overall concept of sustainable development. The introduction of culture as the fourth dimension of sustainable development makes it possible to define the characteristics of sustainable development in the sector of arts and culture. Cultural values can be used in policymaking and sustainable development strategies and are practically applicable in artistic and cultural organisations and businesses. Artistic and creative values can be used, for example, in defining the criteria for assessing the sustainability of a particular policy, organisation, or company and in defining criteria that make it possible to evaluate the contribution of culture to the process of sustainable development and creation of product or image.

Depending on the circumstances and goals, all three cultural roles are important as everything depends on the context. The presented roles are not an evolutionary path to follow, but in this three-role system, certain trends, dynamics, and trajectories can be seen. Policies are becoming more diverse and multilayered, requiring a broader understanding of the sustainable development process, a dialogue, and ongoing interdisciplinary cooperation. It is clear that conceptualising culture as an equivalent component of sustainable development expands the definition of culture, which requires a systemic approach encompassing both natural and human-made worlds.

TABLE 2.1

Links between the Sustainable Development Goals and Culture

SD Goal No	Sustainable Development Goal	The role of culture in implementing the Sustainable Development Goal
Goal 1	End poverty in all its forms everywhere. Indicators: 1. The access to use chosen infrastructures of the cultural community (museums, libraries, media resource centres, exhibition venues for performing arts) compared to the distributions of the country population in administrative units below the state level. 2. Men and women with the ability to reach the main cultural services and resources (libraries, community centres, art centres, museums, local heritage conservation centres, etc.) in 30 minutes by foot.	Cultural services are services that shall be accessible to all, ensuring equal access to them by paying particular attention to poor and vulnerable individuals. The creation of cultural expression, services, goods, and heritage sites may contribute to inclusive and sustainable economic development.
Goal 2	End hunger, achieve food security and improved nutrition, and promote sustainable agriculture.	Traditional knowledge that allows preserving the existing genetic resources should be recognised and maintained in each area. In this way, it is possible to reduce the threat of famine and improve local population nutrition opportunities by using genetic seed diversity and promoting fair payments in agriculture. The sustainable development of agriculture can be promoted by using traditions of cultivation, livestock farming, and horticulture.
Goal 3	Ensure healthy lives and promote well-being for all at all ages.	New health policies and healthy lifestyle promoting programmes must be culturally relevant. Local customs, which can be integrated into traditional healthcare systems, play an important role here. Individual participation in the cultural life of the country can also improve their health and overall well-being.

(*Continued*)

TABLE 2.1 (*Continued*)

Links between the Sustainable Development Goals and Culture

SD Goal No	Sustainable Development Goal	The role of culture in implementing the Sustainable Development Goal
Goal 4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. Indicators: 1. The percentage of teaching hours for art education, taking into account the total amount of teaching hours in the first two years of secondary school (grades 7–8). 2. The percentage of workers in primary and secondary education with special training in artistic and cultural disciplines. 3. The percentage of primary and secondary schools with a library. 4. The percentage of the population who have participated in cultural activities at least once in the last 12 months. 5. Global Cultural Engagement Index (and related indicators).	Aspects of cultural diversity, art education, languages, and culture that play an important role in sustainable development should be integrated into education programmes of all levels. Cultural approach, including the recognition of local languages and local level skills, and participation of interested cultural parties must be prevailing in creating education programmes at all levels: it complies with human rights and can contribute to the educational objectives, including student motivation and community relations. This goal can be achieved by ensuring that all learners acquire the knowledge and skills needed to promote sustainable development. It requires the use of assessment of the sustainable development and sustainable lifestyle, human rights, gender equality, peace and non-governmental cultural promotion priorities as well as the assessment potential for global citizenship development, cultural diversity, and contribution of culture to the sustainable development.
Goal 5	Achieve gender equality and empower all women and girls.	Gender equality should be achieved in cultural life as well. It requires widening the opportunities for women and girls to take an active part in cultural life and manage their projects and organisations in this field. Cultural practice, which is mainly run by women and girls, must be more visible and acknowledged. Narratives that talk about gender discrimination or show the importance of the role of women and girls in cultural life are necessary.

(*Continued*)

TABLE 2.1 (*Continued*)

Links between the Sustainable Development Goals and Culture

SD Goal No	Sustainable Development Goal	The role of culture in implementing the Sustainable Development Goal
Goal 6	Ensure availability and sustainable management of water and sanitation for all.	Traditional knowledge, values, and customs can provide an opportunity to learn how to use ecosystems properly, which is directly related to clean water availability and sanitation.
Goal 7	Ensure access to affordable, reliable, sustainable, and modern energy for all.	Certain cultural factors can be used as models for energy generation and consumption. By employing traditional businesses and cultural heritage knowledge, creative people can participate in creating educational and awareness-raising activities related to energy generation and consumption, especially in the field of energy efficiency.
Goal 8	Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all. Indicators: 1. The percentage of people employed in the cultural sector of the total working population. 2. The percentage of UN development assistance systems, national development plans, and local development plans integrating culture. 3. Contribution of creative and cultural activities to the gross domestic product. 4. Index of interface and coverage of technical and vocational training and higher education systems in the field of art and culture. 5. The percentage of countries that implemented/adopted social security and tax laws and regulations for self-employed artists according to 1980 UNESCO recommendation on the status of an artist.	Cultural and creative sectors can become areas of inclusive, sustainable, and fair employment if decent working conditions, which are in line with international human rights, are ensured. Cultural aspects can be integrated into tourism strategies. It is essential to ensure that cultural identities, as well as related activities and assets, would not be deco-desexualised and that the benefits would be reinvested into cultural activities. This goal can be achieved by supporting productive activities, job creation, entrepreneurship, creativity, and innovations in the development of small- and medium-sized enterprises, taking advantage of local access, human resources in the regions and isolated areas, and adequate funding. Sustainable tourism promotes local culture, which, in turn, creates jobs and culturally promotes the development of valuable products.

(*Continued*)

TABLE 2.1 (*Continued*)

Links between the Sustainable Development Goals and Culture

SD Goal No	Sustainable Development Goal	The role of culture in implementing the Sustainable Development Goal
Goal 9	Build resilient infrastructure, promote inclusive and sustainable industrialisation, and foster innovation. Indicators: 1. The number of countries that implement the national strategy of creative industry development.	If the cultural infrastructure is properly designed, it ensures affordable and equal access to cultural life as a part of the high-quality, reliable, sustainable, and resilient infrastructure that should be accessible to all. Artists and creative individuals can participate in processes of research, development, and innovations in various industrial areas.
Goal 10	Reduce inequality within and among countries.	The participation of individuals in cultural life contributes to reducing inequality since the participation must not be restricted by age, gender, disability, race, ethnicity, religion, economic, or another status. Artists and creative individuals have the opportunity to participate in the process of creating and presenting narratives that give an exclusive status to developing countries. All approaches to migration should include the cultural aspect and intercultural dialogue.

(*Continued*)

TABLE 2.1 (*Continued*)

Links between the Sustainable Development Goals and Culture

SD Goal No	Sustainable Development Goal	The role of culture in implementing the Sustainable Development Goal
Goal 11	Make cities and human settlements inclusive, safe, resilient, and sustainable. Indicators: 1. The percentage of national and local urban development plans that include a specific "cultural impact assessment". 2. The number of identified cultural and natural heritage objects (objects and artefacts). 3. The number of dangerous natural and cultural heritage objects. 4. The number of public libraries per 1,000 inhabitants. 5. The percentage of the budget allocated to the preservation of cultural and natural resources. 6. Multidimensional system development index of heritage sustainability. 7. The part of cities with the integrated urban policy that protects cultural and natural heritage. 8. The part of urban land for open public spaces (streets, squares, gardens, parks, etc.). 9. The part of urban land for public protected premises (libraries, museums, etc.).	Many important objects and elements of tangible and intangible cultural heritage are located in cities and play an important role in sustainable local development; indeed, cultural aspects are essential in promoting sustainable local development. Green and public spaces can contribute to the development of local cultural activities and must be accessible to all. Traditional construction methods, knowledge, and local materials can provide information on the renovation of existing buildings and the design of new buildings. Cultural factors inform about behaviour in cities, including transport and mobility, usage of environment, etc. The implementation of this goal enables the strengthening of efforts in the area of global cultural and natural heritage protection by ensuring universal access to safe, inclusive, and accessible green and public spaces, particularly for women and children, the elderly and the disabled.
Goal 12	Ensure sustainable consumption and production patterns. Indicator: 1. The percentage of national and local sustainable tourism development strategies involving the culture section.	Local and traditional products that are suitable for promoting sustainable consumption must be recognised and valued in order to achieve the goal.

(*Continued*)

TABLE 2.1 (*Continued*)

Links between the Sustainable Development Goals and Culture

SD Goal No	Sustainable Development Goal	The role of culture in implementing the Sustainable Development Goal
Goal 13	Take urgent action to combat climate change and its impacts. Indicator: 1. The percentage of national and local climate change strategies that consider the role of the cultural aspect of promoting environmental sustainability.	Intercultural activities and traditional knowledge of environment-friendly practices must be explored and promoted. Cultural professionals have the opportunity to inform the public about climate change and its consequences through cultural activities.
Goal 14	Conserve and sustainably use the oceans, seas, and marine resources for sustainable development.	The goal can be implemented by identifying and strengthening certain cultures that maintain traditions related to the preservation of marine and coastal ecosystems.
Goal 15	Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation as well as halt biodiversity loss.	Cultural factors related to the preservation of terrestrial ecosystems including relevant local and traditional knowledge must be included in the preparation, implementation, and evaluation of policies and programmes in this field.
Goal 16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable and inclusive institutions at all levels. Indicators: 1. Laws ensuring the right to receive information from public institutions, based on international standards. 2. Legal regimes ensuring compliance with international standards on freedom of expression, association, and assembly. 3. The percentage of libraries regularly providing specific training on media and information literacy competences in order to help users access and use information.	In order to implement this Sustainable Development Goal, nationalised and otherwise expropriated cultural objects should be returned to the concerned communities. Citizens should be able to participate in the preparation, implementation, and assessment of cultural policies and programmes. Cultural objects, including libraries and media centres, promote access to the information. Strategies that condemn violence and promote peace shall also include a cultural component.

(*Continued*)

TABLE 2.1 (*Continued*)

Links between the Sustainable Development Goals and Culture

SD Goal No	Sustainable Development Goal	The role of culture in implementing the Sustainable Development Goal
Goal 17	Strengthen the means of implementation and revitalise the Global Partnership for Sustainable Development.	The cultural aspect should be integrated into international, national, and local sustainable development strategies seeking to implement the 2030 Agenda. The capacity of cultural stakeholders to address the challenges of sustainable development should be strengthened, whereas capacity building should also enable other sustainable development groups to understand the importance of cultural aspects. The capacity of cultural stakeholders to produce and distribute cultural goods and services, particularly those representing lesser-known cultural expressions, should be increased.

Source: Created by authors.

2.2 The Link between Sustainable Development and Climate Change

A close link exists between sustainable development and climate change. Since their main connection is energy, it is necessary to examine how policies of sustainable development and climate change can be identified and implemented together. A system of indicators is necessary to establish a link among the Millennium Development Goals (which are the key targets of sustainable development policy), national development, and climate change mitigation programmes.

In the Third Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), a chart linking climate change, natural systems, people, and opportunities for socio-economic development was introduced.

In Figure 2.1, the interaction between the climate change mitigation policy and adaptation efforts is presented.

Figure 2.1 vividly illustrates how paths of socio-economic development affect GHG emissions as well as climate change, which leads to changes in human and natural systems.

Following the IPCC report, several studies had emerged that addressed climate change and sustainable development in a comprehensive manner. These studies aimed to establish a clear divide between natural processes

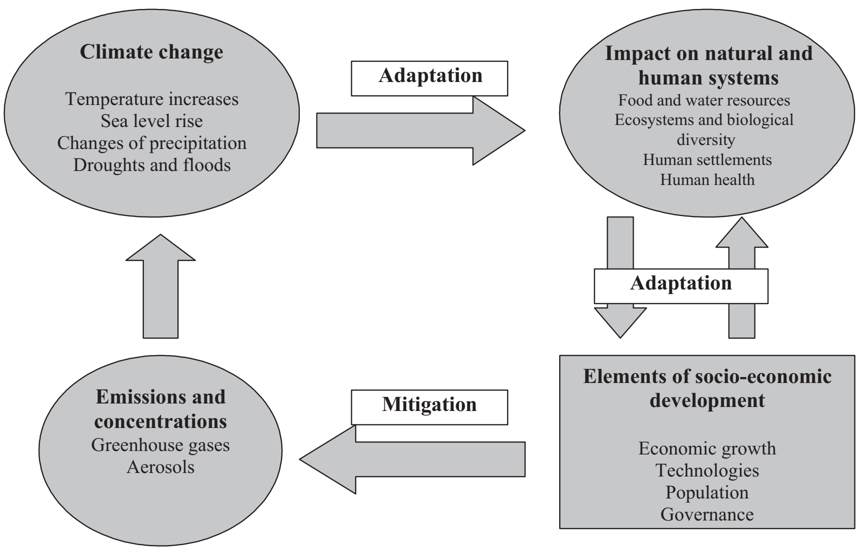

FIGURE 2.1
Interaction among policies of sustainable development, adaptation, and climate change mitigation.

Source: Created by authors.

with their outcomes and their relation to human and social activity outcomes, which are determined by the implementation of policy provisions. These policies include direct climate change mitigation measures as well as more general policies that impact vulnerability due to climate change together with adaptation and mitigation capabilities.

Furthermore, we will examine the options for sustainable development, climate change, adaptation, and mitigation as well as their links in more detail. When it comes to climate change mitigation and adaptation, it must be recognised that these processes are influenced by the trajectory of development together with institutions implementing it and by the specific options available for climate change mitigation and adaptation. This means that policy-driven development trajectory and institutions implementing it, despite their broader development targets, have an indirect impact on climate change adaptation and mitigation.

This impact can be both positive and negative. Several studies had been developed that proposed integrating climate change mitigation and adaptation into development policies to ensure more sustainable development (Munasinghe 1991).

Kenneth Joseph Arrow proposed a method to assess alternative options for consumption growth in the long run from a sustainable development perspective. Intermediate consumption and usefulness are used as criteria for assessing sustainable development. One of the determinants of consumption and usefulness is the productive base of society, which consists of capital (productive, human, natural) and institutions. Institutions can be understood as a part of the capital as well as a guide for resource (and capital) distribution. Institutions cover the legislative framework, formal and informal markets, various state agencies, interpersonal networks, and the rules of conduct and the norms on which they base their activities (Arrow et al. 2012).

From the perspective of sustainable development, it is important how and to what extent policies can affect the productive base of society, while ensuring that the development trajectory is more sustainable when implementing certain adaptation and mitigation policies.

Policy on climate change mitigation or adaptation can be considered as a starting point, while sustainable development can be seen as a result of the indirect influence of this policy. This approach is focused on more specific sectoral policies or climate change policy instruments that ensure adaptation and mitigation targets but are not necessary for all dimensions (social, economic, and environmental) of sustainable development. This shows that climate change policy will be held back by the compatibility of development goals with the global environment. Besides, policies that fail to assess the economic and social consequences may remain unsustainable for a long time.

The next figure presents a chart of interaction among climate, natural systems, and society as well as the impact of policies among themselves.

Figure 2.2 shows three systems represented by ellipses: climate change, natural system, and socio-economic system. GHG emissions affect the climate

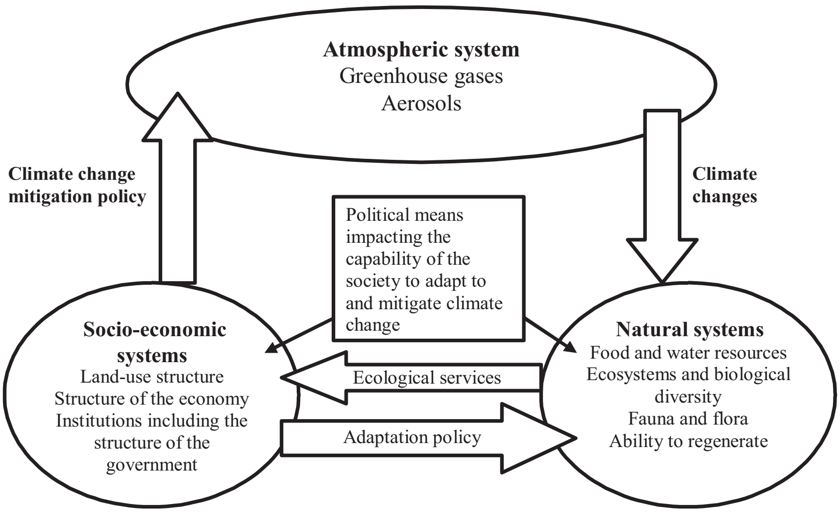

FIGURE 2.2
Interaction among climate, natural, and socio-economic systems and their connection with climate change adaptation and mitigation.

Source: Created by authors.

system and cause climate change, which impacts the natural system again. The impact of climate change on the natural system depends on the vulnerability of the system and its ability to resist those impacts. As a result, ecological services are provided to the public such as agricultural land, fishery resources, water resources, etc. It should be stressed that the mutual influence of all systems is complex and non-linear, making it difficult to assess all aspects of the links among them.

The response to climate change depends on the productive base of society, which includes capital, institutions, and adaptation and mitigation capabilities. Policies aimed at ensuring the productive base of society and the capacity for adaptation and mitigation are presented in Figure 2.2 and grouped in one division. In addition, the policies that are divided here have many synergistic effects, which together affect the natural system and the achievement of Sustainable Development Goals.

In this conceptual framework, adaptation and mitigation policies are treated as more isolated policy efforts such as investments in protective measures (dams, new types of crops, technologies to reduce GHG emissions, carbon taxes, etc.), which only affect the marginal response of the production base of society. The factual outcome of specific mitigation and adaptation policies depends on adaptation and mitigation capacities that are part of the social, economic, and natural state of systems. Together, the results of adaptation and mitigation policies depend on the propulsion of social and economic development such as investments, technologies, population, governance, and environmental priorities.

> Dual-link: climate change → sustainable development and sustainable development → climate change

There is a dual-link between climate change and sustainable development. On the one hand, climate change affects the main natural and living conditions together with the social and economic development foundations, but, on the other hand, society's sustainable development priorities impact both vulnerability and GHG emissions.

Many discussions on the links between sustainable development and climate change were initiated in the IPCC Third Assessment Report. The synthesis report stressed the importance of understanding the links between climate change and sustainable development and concluded that climate change issues are a part of the broader challenges of sustainable development. As a consequence, climate change policy can be much more effective if it is consistently integrated into the wider regional and national sustainable development strategies since the climatic diversity and changes, the response to climate change policies and the related socio-economic development will affect the country's capacity to implement Sustainable Development Goals. And vice versa, the realisation of the Sustainable Development Goals will impact the potential of climate change policies and the success of their implementation. The socio-economic and technological characteristics of different development trajectories will have a huge impact on GHG emissions, climate change and its influence, and the capacity to adapt and mitigate climate change.

The key findings of the IPCC are more conceptual and confirm that sustainable development can serve as a framework for understanding society's ability to respond to climate change.

Climate change will also affect sustainable development: due to the negative impact of climate change on ecosystem services, human health, agricultural production, and many other areas, it will be more difficult to implement Sustainable Development Goals. The impact of climate change on development perspectives has been described as a comprehensive poverty reduction and climate change mitigation project "Climate change will complement existing poverty". The negative effects of climate change will be stronger in developing countries, as the latter have limited capacity to adapt to climate change. In these countries, the poorest sections of society with the least resources and the least capabilities to adapt will be the most vulnerable. Predicted changes of extreme climate events in their frequency, power, and intensity as well as average climate changes will mainly affect their quality of life and continue to increase inequalities between the developing and developed world. Thus, it can be stated that climate change is a strong source of poverty growth.

By recognising the dual-link between sustainable development and climate change, it must be stressed that policies shall simultaneously cover both sustainable development and climate change mitigation and adaptation targets.

2.2.1 Development Targets and Sustainable Development Tasks

The concept of sustainable development had been long discussed in the theoretical literature until it became the most significant target in economic, social, and environmental development of Agenda 21, UN institutions, national governments, and private individuals. There are many definitions of sustainable development, but here we will use a significantly pragmatic perception of sustainable development as the goal of human well-being both from a short- and long-term perspective.

The simplest concept of sustainable development is defined as co-development ensuring economic, social, and environmental development targets. These targets can be expressed by a number of economic, environmental, human, and social indicators, while the impact of the implemented policies on sustainable development can be assessed both quantitatively and qualitatively. Table 2.2 provides examples of the main dimensions of sustainable development.

As a starting point for the links between sustainable development and climate change, basic Sustainable Development Goals such as health, education and energy, food, and access to water can be achieved through good governance and without impacts of climate change. Thus, the Sustainable Development Goals are addressed together with the current development targets and the challenges of achieving them.

Using such a pragmatic approach to the concept of sustainable development requires the acknowledgement that the main conceptual assumptions are based on the key development paradigms and analytical approaches which are used in many sustainable development studies. The perception of development goals and the discovery of a compromise among different policy targets depend on the applied development paradigm. Therefore,

TABLE 2.2

Examples of Economic, Environmental, Human, and Social Dimensions of Sustainable Development

Economic Dimensions	**Human Dimensions**
Economic growth	Training and education
Investments	Health
Technological changes	Gender
Revenue in specific areas	
Environmental dimensions	**Social dimensions**
Atmospheric pollution	Governance
Water pollution	Income distribution
Waste	Participation
Biodiversity	Justice
Depleting resources	

Source: Created by authors.

in this chapter, we will show how policy recommendations on sustainable development and climate change depend on alternative approaches to the development itself.

A system of sustainable development indicators aimed to measure policy decisions at the lowest and highest levels, called Action Impact Matrix (AIM), was developed by Mohan Munasinhge. AIM links national development targets and programmes with the assessment of sustainable development indicators and the involvement process of governmental authorities, academic and civil society as well as the private sector.

Alternative development paradigms: The development targets of different paradigms, as well as different scientific disciplines, are treated differently. The development approach in paradigms is the basis on which the key elements, necessary to be evaluated in order to establish the link between development and climate change and its dynamics, are determined. Further, we will examine many development paradigms and their impact on climate change mitigation studies.

Paradigms based on economic theories usually define a number of goals that are important contributions to the well-being of people. In this case, development goals can be perceived as functional elements of a certain value. The value function reflects the results of individual utility by using various goods and services.

Some economic paradigms rely on the economic welfare function, where efficient resource allocation is approached as in neoclassical economics, while deviations from this state and ways of overcoming these deviations are not addressed. From the point of view of these paradigms, the link between sustainable development and climate change is approached as a simple statement that climate change mitigation only leads to additional costs for optimal status.

Meanwhile, other economic-based paradigms, such as institutional economics, are more focused on formulating a question: how do markets or other information-sharing mechanisms provide the basis for economic interaction? In this context, the main idea is how mitigation policies can be integrated into the institutional framework of the economy. Thus, the institutional approach to climate change analysis involves the assessment of the work of existing institutions and making proposals on improving their work by assessing market weaknesses and limited capacity. Furthermore, institutions include governance and political systems that are the main factors for determining development trajectories.

For example, Partha Dasgupta recommends studying the allocation of resources as a counterpoint to the effects that can be measured by parameters of well-being. Possibility to get an income and meet basic needs (education, food, energy, medical services) is considered the basis of the human being (Dasgupta 2000, 2003).

In the context of climate change mitigation policies, it should be examined whether and to what extent, policies may impede or facilitate access of individuals to specific resources and freedoms. In some cases, mitigation policies may prove to be too expensive if more expensive types of energy carriers are introduced, while, in other cases, they may increase the access to energy if energy conservation measures are introduced and energy becomes more affordable.

This approach is close to the paradigms of social sciences, which are based on the ethics of liberalism or equalisation and emphasise the rights of individuals to participate in decision-making and goal achievement processes. These theories shape the assurance of individual freedoms, so issues such as the link of risk and justice with climate change will be addressed by studying the local participatory process.

Development trajectories: When analysing possible development trajectories, it is very important to recognise that several different definitions of sustainable development exist based on the concept of sustainable development established by the Brundtland Commission.

If we regard sustainable development as the policy target, then the important question is how policies can ensure a more sustainable development trajectory. Society's development trajectory is exposed to many important decisions relating to investments, use of natural resources, lifestyle and consumption, selection of technologies as well as the institutional structure, which leads to the base conditions of these choices. All of this can be achieved through sustainable development policies.

Sustainable development policies cannot be strictly separated from other policies; however, a variety of policy recommendations, which cover different components, can still be discussed. They include many policies related to nature conservation, laws regulating access to resources, environmental taxes, promotion of organic agriculture, the increasement of human and institutional capital, research and development, financial schemes, and technology transfers. These policies are usually not implemented as a part of the general sustainable development policies package, but as policies, dedicated to addressing specific policy targets such as air pollution standards, organic food and health issues, GHG emission reduction, income generation for specific groups of people, or the development of green technology industry. In this way, the development trajectory is obtained as a result of many economic and social transactions initiated by governmental policies, private sector initiatives, and choices of consumers.

There are a great number of scientific studies, which are based on economic theories and complex systemic methodology, ecological science, as well as other methodologies and determine the conditions under which the development of the trajectory meets the sustainable development requirements. Arrow summarised the controversy of discussions between economists and ecologists concerning the nature of current development and its compliance with the criteria of sustainable development. Economists are looking into the ability of the economy to maintain an adequate standard of living and state that welfare should be optimised to ensure that current consumption is not excessive. However, it is difficult to determine the optimal level of current consumption; thus, the theoretical debate revolves solely around the factors leading to development that is not sustainable. Those factors include the link between market return on investment and social discount rates and the link between market prices for goods and their social costs.

2.3 Implementation of Sustainable Development and Climate Change Policies

The impact of climate change policy on development policies: Studies aimed at evaluating the impact of sustainable development on climate change and vice versa explore a number of current development challenges. Here, we will overview international policy initiatives and solutions that include development goals as well as discuss how climate change issues can be addressed in conjunction with development goals. We will also look at many examples of how countries that have formulated development goals also consider mitigation aspects of sustainable development.

Many international initiatives, including the World Summit on Sustainable Development 2002 (WSSD) and the actions of the Commission on Sustainable Development, have set many different goals for different sectors related to climate change mitigation policies. We will take a look at these initiatives below.

The main decision of the World Summit on Sustainable Development was the confirmation of the Water, Energy, Health, Agriculture, and Biodiversity (WEHAB) initiative's connection with sustainable development (World Summit on Sustainable Development 2002). The WEHAB sectors reflect the main areas in which WSSD countries consider it necessary to establish policies in order to implement Agenda 21. The justification document prepared for the WEHAB presents numerous policy measures in different sectors that relate to climate change issues. Below a description of the main sectors and policies is presented.

Water: Ensuring safe water supply, water management, agricultural efficiency, human health, disaster preparedness, financial resources, institutional and technical capacity, and protection of water systems.

Energy: Accessibility, efficiency, renewable energy, advanced organic fuels, and transportation.

Health: Reduction of poverty and malnutrition, access to health services, reduced infant, child and maternal mortality, control and eradication of major diseases, planning, link with the environment, risk management capacity, and crisis preparedness.

Agriculture: Increasing productivity and sustaining the natural foundation, knowledge generation and information transferring, partnerships between public and private sectors, and political and institutional reforms.

Biodiversity: Integrating sustainable development into economic and sectoral development plans, and restoring and protecting biodiversity.

Aspects of climate change policy can be linked to the Millennium Development Goals (MDGs). Commission on Sustainable Development stressed that climate change could only worsen the situation of the poor and hinder the implementation of the Millennium Development Goals. SDS has proposed to complement the MDGs with energy development tasks to strengthen the connection between the MDGs and climate change mitigation.

MDGs could be linked to energy, food, water access, and climate change impacts as well as vulnerability and adaptation (Table 2.3).

The basis for the joint implementation of sustainable development and climate change policies is illustrated in Figure 2.3. It consists of the general state of the natural environment, the socio-economic system, and policy priorities. The latest international trends in sustainable development and management of climate change are the increasing involvement in these processes by various institutions and other stakeholders. These stakeholders include international agencies, global forums, private companies, and non-governmental organisations. The involvement of various stakeholders in this process creates new opportunities to combine international agreements and commitments with voluntary action and market-driven processes. Several new initiatives by private efforts are to combine green business, sustainable development, and climate change mitigation.

Many companies have included voluntary commitments in their development strategy reflecting their social responsibilities and environmental goals that go beyond their traditional responsibilities. The majority of companies voluntarily commit to reducing GHG emissions. Several international networks are promoting these initiatives: World Business Council for Sustainable Development (WBCSD), The Climate Group, etc. These initiatives serve as platforms for collaboration among companies, non-governmental organisations, governments, and other stakeholders.

WBCSD has identified the following main targets for private companies in order to mitigate energy and climate change:

- to ensure long-term success in a competitive business environment;
- to achieve the objectives of national and regional climate change mitigation policies;
- to assess risks and economically effective options for reducing pollution; and
- to participate in the innovation process of processes and products.

TABLE 2.3

The Link among the Millennium Development Goals, Energy, Food, Access to Water, and Climate Change

Goals	Sectoral Subjects	Relations to Climate Change
From 1990 to 2015, to reduce the proportion of people whose income is less than 1 USD a day	Energy: • Energy supply to local businesses • Facilitation of income generation • Energy supply to the equipment • Employment related to energy supply Food/water: • Increment of food production volumes • Improved water supply • Employment	Energy: • GHG emissions • Increased adaptive capacity due to higher incomes and reduced dependence on natural energy sources Food/water • GHG emissions • Increased agricultural productivity can reduce climate change • Better water supply management can help adaptability
From 1990 to 2015, to reduce the proportion of people who suffer from hunger	Energy: • Energy supply for machinery and irrigation equipment in agriculture Food/water: • A more efficient production process which increases production volumes and reduces waste • Land and food distribution	Energy: • GHG emissions Food/water: • Increased GHG emissions from some agricultural activities; however, it is partly offset by better use of agricultural waste • The ability of farmers to adapt depends on the income and the form of land ownership

(*Continued*)

TABLE 2.3 (*Continued*)

The Link among the Millennium Development Goals, Energy, Food, Access to Water, and Climate Change

Goals	Sectoral Subjects	Relations to Climate Change
To ensure that by 2015 children will have access to primary education everywhere	Energy: • Reduced time to provide energy • Electricity for reading • Electricity for educational information means, including TV and computers Food/water: • Shorter time in this sector allows devoting more time for education • Better health increases children's ability to read	Energy: • Education can strengthen the ability to mitigate climate change Food/water: • Education can strengthen the ability to mitigate climate change
To ensure that girls and boys have equal access to primary and secondary education by 2005 and to the education of any level by 2015 at the latest.	Energy: • Due to modern energy services young women or girls no longer need to provide themselves with energy and they have more free time • New electronic educational tools are making it easier for girls to access information at home Food/water: • Modern agricultural production technologies and improved water supply	Energy: • Education can strengthen the ability to mitigate climate change Food/water: Education can strengthen the ability to mitigate climate change

(*Continued*)

TABLE 2.3 (*Continued*)

The Link among the Millennium Development Goals, Energy, Food, Access to Water, and Climate Change

Goals	Sectoral Subjects	Relations to Climate Change
From 1990 to 2015, to reduce the mortality rate of children under five by two-thirds	Energy: • Energy supply can speed up the development of healthcare facilities • Reduced air pollution from sources that use traditional fuel for combustion • Reduced time spent on collecting fuel may increase time spent on children's healthcare Food/water: • Improved health due to increased supply of high-quality food and clean water • Reduced time spent on providing food and water can increase the time spent on children's healthcare	Energy: • GHG emissions Food/water: • Improved health increases the ability of adaptation
From 1990 to 2015, to reduce maternal mortality by three quarters	Energy: • Electricity supply to health clinics • Reduced air pollution from sources that use traditional fuel for combustion and other health improvements Food/water: • Improved health due to increased supply of high-quality food and clean water • Reduced time spent on providing food and water can increase the time spent on children's healthcare	Energy: • GHG emissions Food/water: • Health improvement increases the vulnerability of climate change and the ability of adaptation

(*Continued*)

TABLE 2.3 (*Continued*)

The Link among the Millennium Development Goals, Energy, Food, Access to Water, and Climate Change

Goals	Sectoral Subjects	Relations to Climate Change
AIDS, malaria, and other serious diseases	Energy: • Electricity for health facilities • Cooling of vaccines and medical devices Food/water: • Improved health due to cleaner water supply • Manufacturing technologies of the food industry that reduce the likelihood of malaria	Energy: • GHG emissions from the increased health clinic service; however, health improvements may reduce the need for health clinics Food/water: • Health improvement increases the vulnerability of climate change and the ability of adaptation
To stop the unsupported exploitation of natural resources	Energy: • Deforestation allows waste fuel to be collected • The usage of non-renewable resources Food/water: • The decline in land ownership	Energy: • GHG emissions • Separation of carbon Food/water: • Separation of carbon • Better conditions in agricultural production increase adaptability
From 1990 to 2015, to reduce the proportion of people who cannot access drinking water	Energy: • Electricity for pumping and distribution systems Water: • Better water systems	Energy: • GHG emissions Water: • Increased vulnerability and adaptability
To expand global cooperation in development		

Source: Created by authors.

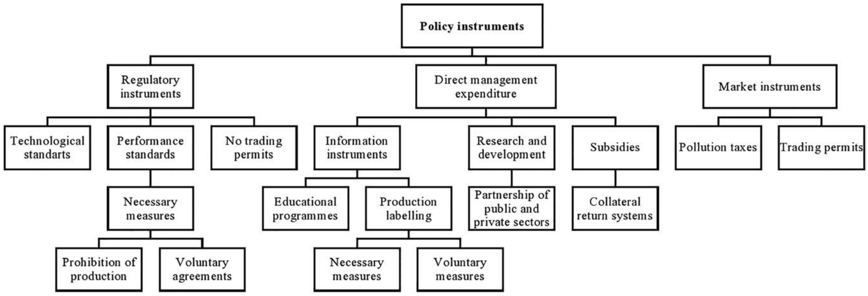

FIGURE 2.3
Measures of the climate change policy.

Source: Created by authors.

The WBCSD has prepared guidelines for monitoring and accounting for GHG emissions under IPCC GHG inventory standards. The WBCSD also emphasised the importance of accounting for GHG emissions in order to demonstrate eco-efficiency and to maintain the company's image of accountability and transparency. In addition, the implementation of this GHG accounting methodology allows companies to participate in emissions trading.

Moreover, insurance companies have their own rules of operation which include activities for ensuring sustainable development and climate change (Munich RE initiative). An example of a non-governmental organisation's initiative combining the goals of sustainable development and climate change mitigation is The Gold Standard prepared by the WWF. The Gold Standard is designed to assess how CDM projects can support the broader Sustainable Development Goals and if they are not included in their GHG reduction tasks.

Climate change mitigation measures: Each country chooses individual climate change mitigation measures. On the basis of the IPCC Third Assessment Report, the following chart of all the climate change mitigation measures is drawn up. Thus, the main climate change mitigation policies can be grouped as follows:

- market-based mechanisms (pollution taxes, emission allowances, subsidies, and collateral return systems);
- regulatory instruments (emission permits, operating and product standards, and prohibitions);
- voluntary agreements; and
- direct government expenditure on research and development (or subsidies/financing of information tools, including educational programs and eco-labelling schemes).

Each of these climate change mitigation measures has its own disadvantages and advantages when comparing with others. The IPCC Third Assessment

Report indicates that various policies that are not related to climate change could influence the dynamics of GHG emissions. These may include structural reforms, for example, the pollution control in the energy sector that is trying to reduce the negative impacts on human health and afforestation for economic or biodiversity's preservation reasons or for salinity control reasons.

The main feature of market-based instruments is that they apply economic incentives to pollution control through pollution taxes and emissions trading allowances. They encourage polluters to adjust to market prices or pollution levels.

Regulatory instruments form the technological and performance standards and project the fuel that is used or the fuel that cannot be used. These types of instruments are applied at a national, sectoral, or company level. They are typically introduced before the market-based instruments and create opportunities for institutional capabilities in the spheres of policy evaluation, monitoring, and enforced implementation.

Voluntary agreements are agreements between a governmental body and a private company, or a unilateral agreement recognised by a public authority. They differ from the regulatory instruments because they are not mandatory and there are no penalties for non-compliance. They demonstrate a mutual responsibility of the contracting parties and are applicable internationally and nationally; they also have low transaction costs and flexibility in implementation.

Information instruments help to overcome the market disadvantage related to the asymmetry of information. Two main information instruments can be used both nationally and internationally: educational programs and eco-labelling. Educational programs are designed to fill knowledge gaps that hinder climate change risk assessment. They also introduce pollution reduction actions such as energy-saving initiatives.

Environmental labelling programs, whether mandatory or voluntary, send signals to users about the characteristics of the equipment (energy efficiency of the equipment). An example of voluntary labelling is the labelling of organic products or ethical trademarks.

The third group of information instruments has recently been identified – informing the industry of long-term indicative goals of the government. For example, the long-term goals for reducing GHG emissions or the tasks of renewable energy sources in the primary energy structure.

An alternative way to tax pollution is the subsidisation of less polluting fuels or energy efficiency improvement measures. Both methods have an impact on energy prices and are favourable for technologies that emit less GHG emissions as well as for clean fuels. Subsidies and pollution taxes are sometimes combined when the taxes for the sold energy are used to subsidise renewable energy.

The following criteria shall be met to select appropriate climate change mitigation measures:

- environmental effectiveness looking from a long-term perspective;
- environmental effectiveness in terms of transaction, information, and forced implementation costs;
- impact on resource redistribution;
- the possibility of administrative and political implementation;
- the dynamic effect related to the learning, innovation, and technological development processes;
- the other economic effect (income redistribution); and
- the other environmental impact (the assurance of ambient air quality).

Countries can select several policies or use them in succession, for example, to introduce technological standards first and then – performance standards. Finally, they could introduce market-based instruments.

Promotion of the spread of innovations and new technologies is a very important means of climate change mitigation. Usually, the government uses subsidies, research funding programs, green purchasing of environmentally friendly technologies as well as a complex of climate change mitigation measures. That way the strengths of the various instruments can be combined, and their negative impact reduced.

Climate change mitigation policy and associated costs include a range of measures used for market development and broader institutional policies (Table 2.4).

When defining climate change mitigation policies, certain assumptions are made in the energy sector (Table 2.5). These assumptions are very important when choosing climate change mitigation policies and justifying the expediency of using the proposed instruments. The most important assumptions are based on population, economy, energy demand growth forecasts, the elasticity of prices and services, discount rate, etc.

Table 2.6 shows the relation between climate change policy and the different dimensions of sustainable development. As can be seen, climate change also has a direct impact on economic growth opportunities and many important social factors as well as political and social issues. In addition, the effects of climate change can be identified domestically and globally.

The most significant thing when selecting the climate change policy and measures for its implementation is to take into account its impact on sustainable development and to harmonise climate change policies with those of sustainable development; otherwise, the climate change mitigation can have even more negative effects than climate change itself. This is particularly the case with developing countries, which are the most vulnerable to climate change but have limited possibilities to adapt to it. Therefore, in these countries, climate change mitigation policies need to be integrated into their country's sustainable development strategies, and their implementation should not hinder the achievement of the MDGs.

TABLE 2.4

Examples of Policy Measure Implementation Related to Climate Change

Market Measures	**An Example of a Policy Measure**
The development of the market during the transitional period, possibly involving the public sector	Temporary support for special demonstration projects
Privatisation with precise identification of property rights and individual requirements	Land ownership rights
Competition regulation by introducing more market players	Information companies, flexible loans for the expansion of technologies that use renewable resources
Environmental taxes	Carbon taxes
Support for efficiency through savings and stimulation of investments	Support by the financing mechanisms
Publishing of technical standards within the relevant period	Standards for the effective use of electrical appliances
Price liberalisation, support for the international competition	Change in the rate of devaluation, elimination of the subsidies
Redirecting Policy towards Flexibility and Constraint of Acknowledged Technical Systems	
Time selection of infrastructure investments	Long-term planning of energy production and transmission
Subsidies for capital turnover projects	Special capital grants
Subsidised credits for research development	Demonstrations and research programmes
Coordination of specific climate change mitigation measures and their integration into the common investment policy	Information, subsidies
Established (Institutional) Policy Measures	
Establishment of monitoring and the enforced implementation systems	Reporting systems
Established and imposed property rights	Land reforms
A structure to mitigate the risk and/or to reduce the accumulated risk (especially in the capital market) is established	A balanced market
Establishment of specialised organisations to reduce uncertainty and transfer information	Insurance schemes
To implement an international mechanism for technology “transfers”	Clean Development Mechanism
Policy Measures Concerning Human Opportunities	
Learning and educational activities	Opportunity development programmes
The improvement of decision-making processes	Participation, local government
Educational programmes	Providing energy and transport for schools

Source: Created by authors.

TABLE 2.5

Assumptions for the Climate Change Mitigation Policy in the Energy Sector

Assumptions Are Introduced	Meaning and Relevance
Population	Growing population increases GHG emissions
Economic growth	A growing economy increases energy consumption and makes it possible to increase investments, which accelerate the growth of the energy-using equipment
Energy needs • Structural change • Technological change • Lifestyle	Different sectors have different levels of energy consumption intensity; structural changes have a major impact on overall energy consumption Different assumptions in the areas of the intensity of GHG emissions and the use of resources can be used for alternative scenarios
Energy supply • Presence of technology and prices • New technologies • Learning	Possibility for fuel and technology replacement Electricity prices that make alternative electricity supply possible Technology costs related to time, market scale, and institutional competence Opportunities for the introduction of new technologies
Elasticity of prices and revenue	Relative changes in the energy needs due to the changes in prices or revenue; higher elasticity results due to larger changes when energy is used
Implementation and contractual prices	The scope of implementation, regulatory framework, institutional competence, administration
Discount rate	Time The potential price of the capital Assumptions of risk Uncertainty
Policy instruments and regulation • Instruments • Obstacles	Economy against the regulatory measures Implementation costs including the cost of overcoming obstacles, the form of institutional aspects or market trends, including building opportunities and institutional reforms; functioning assumptions
Existing tax system and tax refund	Carbon tax refunds; replacement of distorting taxes
Additional benefit	Integration of local and regional policy measures into many production cases Secondary benefit Targets of social policy: income distribution and employment

Source: Created by authors.

TABLE 2.6

The Impact of Climate Change on Different Dimensions of Sustainable Development

Dimensions of Sustainable Development	Impact of Climate Change	
	Domestically	Outside the Country
Economy	Increased vulnerability of agricultural technologies enhances inequality	As the negative effects of climate change in developing countries increase, inequality increases as well
Health	The poorer people suffer from lower general health standards and reduced access to healthcare	Effects of floods and diseases are more important in developing countries
Social security	All sectors are affected but those that depend mainly on natural resources are affected the most	Greater impact in developing countries
Gender	As the main users of natural resources, women are individually affected by climate change	Economic gender inequality increases
Access to the welfare of society	Government cost-sharing to mitigate the effects of climate change impacts everyone, but it will mostly affect the poor	Adaptation costs are higher in poor countries
Political and social freedoms	With the possibility of social destruction, freedoms can be ruined	The impact of migration can be felt in all countries

Source: Created by authors.

2.4 Sustainability Assessment Methods

Sustainability assessment methods can be divided into four key groups: indicators and indices, sustainability assessment means at the level of products (production methods) as well as at project, and country levels. All these means can be further subdivided based on their sustainable development dimensions (environmental, social, economic, integrated, and including all sustainable development dimensions) (Table 2.7).

2.4.1 Indicators and Indices

The first group for sustainability assessment consists of *indicators*. Indicators are a simple tool that allows assessing the economic, social, and environmental development goals of a country. If environmental, social, and economic indicators are integrated into a single indicator, they make an *index*. Indicators must show the following features: simplicity, wide coverage, and an ability to perform a quantitative assessment that helps to determine tendencies. Tendency assessment allows you to make short-term forecasts.

TABLE 2.7

Sustainability Assessment Methods

	Indicators/Indices	Products, Technology Assessment	Project Assessment	Sectoral, Country Assessment
Environmental dimension	Environmental pressure indicators Ecological footprint	Life-cycle assessment Material input per unit of service Material flow analysis Energy flow analysis Exergy analysis Emergy analysis	Environmental impact assessment Ecological risk analysis	Environmental extended inter-branch balance Inter-branch energy balance Strategic environmental impact assessment Regional emergy analysis Regional exergy analysis
Economic dimension	General national production volume	Life-cycle costs	Accounting of all life-cycle costs	Economic material flow analysis Economic flow analysis Economic inter-branch balance
Social dimension	Social indicators		Social impact assessment	Social inter-branch balance
Integrated method	Human Development Index Environmental Sustainability Index Welfare Index Sustainable national income Genuine progress indicator Genuine savings indicator		Cost–benefit analysis Risk analysis	Multi-criteria analysis Vulnerability analysis
Sustainable development	UN Sustainable Development Goal indicators Sustainable energy development indicators			Conceptual framework System dynamics Sustainability impact assessment Integrated sustainability assessment

Source: Created by authors.

All the tools and indicators of this category can be grouped into non-integrated and integrated indicators (indices). Regional flow indicators make a different class.

Environmental Pressure Indicators (EPIs), prepared by the European Union Statistical Office EUROSTAT (European Commission and Eurostat 1999, 2001), are an example of non-integrated indicators. EUROSTAT collects these indicators for EU member states and regions, in co-operation with the statistical departments of these countries. EPI consists of 60 indicators, 6 indicators for each political sphere, set by the Fifth Environmental Action Programme (Lammers and Gilbert 1999). In each political area, these six indicators may be aggregated into indices, which, in turn, make up ten environmental pressure indices. The entirety of these indicators, which consist of, e.g. damage to forests, the intensity of tourism, and polluted soil, is dedicated to assessing the environmental protection sustainability of EU member states. These indicators allow the comparison of countries and the assessment of their tendencies.

Another example of non-integrated indicators is the collection of 58 indicators, used by the United Nations Conference on Sustainable Development (UNCSD 2001). These indicators include not only the economic, environmental, and social dimensions but also the institutional dimension. Such an indicator system is not integrated. Examples may include water quality level, national literacy rate, population growth rate, gross domestic product (GDP) per capita, and a number of ratified international agreements. Since 1994, based on these indicators, countries have been preparing reports to the European Commission and accounting for their results of meeting sustainable development goals (United Nations 2002).

Sustainable Energy Development Indicators include social, economic, and environmental energy sector dimensions. The indicator system was created by the International Atomic Energy Agency, EUROSTAT, and United Nations. These indicators are not integrated and are used for the sustainability assessment of the country's energy sector. By using these indicators, it is possible to assess the sustainable energy development tendencies and take proper actions to change or promote these tendencies.

Material and Energy Flow Analysis allows analysing the resource flow structure and finding inefficient manifestations in the system. This indicator class can be used for historical reconstruction of flows and emissions as well as decision-making. Material Flow Analysis (MFA) analyses physical metabolism of the society in order to support dematerialisation processes and to reduce the negative impact on the environment, related to wasteful resource usage (Kleijn and Adding 2001). MFA studies have been performed in many countries and regions (Fischer-Kowalski and Hüttler 1998). In addition, the number of MFA has significantly increased in recent decades. This indicator class is non-integrated; these indicators include only physical flows, so they analyse the environmental dimension. MFA of all economy, calculated by EUROSTAT (2001), is a standard MFA tool for the EU countries.

World Resources Institute MFA studies for the developed world countries were the initial tool to standardise MFA in the European Union. EUROSTAT has prepared guidelines for the MFA economy assessment. In the EUROSTAT guidelines, material flow indicators are divided into three categories: input, outflow, and consumption. Each category includes different levels based on whether it involves local, foreign, or hidden flows. Hidden flows are the flows that are not included in the economic system, i.e. excavation, soil erosion, etc. (Matthews et al. 2000).

Material Input Indicators show material inflow into the economy through local production and consumption. *Material Outflow Indicators* measure all material outflow back to the environment or pollutants disposed of to the environment during the production or consumption processes. *Material Consumption Indicators* measure all material consumption in the economy.

Substance Flow Analysis (SFA) involves the regional flows of certain chemical materials and environmental losses related to them (Lindqvist and von Malmborg 2004). The goal of the SFA is to reduce the pressure of certain materials to the environment. The SFA is carried out at a regional or country level to identify problematic areas. It is useful for planning and managing an environmental policy.

Energy Flow Analysis covers energy flows in the economy. It is based on the first law of thermodynamics or energy persistence, which states that the amount of energy is constant, cannot be created or destroyed, and can only transfer from one form to another. Energy analysis of a country or a region is performed by using the *input–output energy analysis,* based on Wassily Leontief's economic input–output matrix, which analyses flows among different industry branches in the economy. In the case of energy flow analysis, among industry branches or sectors, sale flows are changed to energy flows (Finnveden and Moberg 2005).

In addition, energy analysis can be performed by using *exergy and emergy analysis*. This analysis is advanced because both the quality of energy and its quantity are considered during it (Rosen and Dincer 2001; Herendeen 2004). System exergy is the maximum amount of mechanical work that can be generated. Exergy analysis shows the efficiency of material usage and where losses form as well as where technological upgrades can be made in order to increase the efficiency of energy. The results of regional exergy analysis, conducted in Sweden, Japan, and the United States, allowed preparing the methodology of regional emergy analysis, the base of which is constituted of the expression of all resources and goods in a single unit of measurement – solar emjoules, i.e. the amount of solar energy needed to produce them.

There are many efforts to integrate sustainable development indicators in order to create one index that reflects the achievements of sustainable development (Gerlagh et al. 2002). The first efforts were directed towards supplementing new indices of national report systems such as GDP and net national income, which are meant for general welfare assessment. The latter sent false signals about the level of the achieved welfare since the achievements of sustainable development such as income distribution inequality, public safety, material overexploitation, or non-evaluation of external costs had not been assessed.

A larger variety of GDP modifications were proposed because of its limitedness in assessing environmental dimensions and willing to set an adequate life quality indicator. All of them were meant for the performance assessment of sustainable development.

Sustainable National Income (SNI) is an index created in the Netherlands. The main point of this index is GDP modification that includes sustainable resource consumption into the national income report. SNI does not directly assess social factors. It is a comparison of national income, calculated by principles of sustainability, and traditionally calculated national income. The difference between these two values shows the dependency of a country on production resource consumption that exceeds sustainable resource consumption calculated by logistic growth models (Gerlagh et al. 2002).

Index of Sustainable Economic Welfare (ISEW), created by Herman Daly and John Cobb, as well as the *Genuine Progress Indicator* (GPI), created by the organisation Redefining Progress, involves economic, social, and environmental dimensions. All these indicators are GDP modifications by adjusting national account modifications in order to include a larger number of welfare determinants such as military expenditure, environmental degradation, and natural capital depreciation. They have been calculated for many countries.

Genuine Savings Indicator (GSI) is meant for national-level sustainability assessment. This indicator is applied in the studies and reviews of the World Bank. It includes resource decay and environmental degradation indicators as well as technological changes, human resources, the export of depleting natural resources, resource discovery, and critical natural capital. Economic and environmental components are emphasised the most, but it also covers investments and education. The positive indicator value shows positive movement towards sustainability, while the negative indicator presents the movement in the opposite direction. Its advantage is that it gives a clear signal to a country about the direction of its sustainability.

Ecological Footprint is an indicator which rates resource consumption and waste formation for a certain area of land and is calculated on a country or regional scale. Ecological footprint calculation consists of a few steps. First, the average yearly food, living space, transport, product, and service consumption per capita are calculated. The land plot required to make each of the consumption needs is calculated after that, and its environmental impact based on the needed land plot is assessed. Then, after adding those land plots, a land plot required to fulfil yearly needs per capita is derived. It has been calculated for many countries and regions and is dedicated to assess the sustainability of the country; however, it can also be applied to a city or a region.

Aggregated indices are also calculated. *Welfare Index* (WI) was used in order to rate the progress of Parties of the Johannesburg Earth Summit 2002 in their sustainable development. It was calculated for 180 countries. This index consists of two indices: the *Human Welfare Index* (HWI) and the *Ecosystem Welfare Index* (EWI), which includes more than 60 aggregated indicators. HWI involves human and health parameters, wealth indicators as well as indicators of knowledge, culture, community, and equality. EWI involves dimensions of the earth, water, and atmosphere, indicators of biodiversity, and resource consumption. When they are connected to WI, these indices are given equal weight. The Barometer of Sustainability is applied for the procedure of connecting these indicators to WI.

Environmental Sustainability Index was formed in order to rate the progress achieved in sustainable development. It consists of 68 indicators that involve five different categories: the condition of environmental systems (air, water, soil, ecosystems, etc.), reduction of stress on environmental systems, reduction of human vulnerability due to environmental changes, social and institutional abilities to deal with environmental challenges, and strengthening of international standards and requirements. Even though this index assesses environmental sustainability, it also involves social and institutional dimensions. Its goal is to compare countries based on their ability to make environmental decisions.

Since 1975, the *United Nations Development Programme (UNDP)* prepares annual global reports on social human development. *Human Development Index (HDI)* of 175 countries is calculated in the report; according to it, Lithuania takes the 45th rank. HDI is a composite unit of human development.

HDI *measures the average achievements of a country based on three key components of social human development*:

- long and healthy life, which is testified by the future average life expectancy;
- knowledge and education, as measured by the adult literacy rate (two-thirds of the component weight), and the combined coefficient of those who are trying to get primary, secondary, and tertiary education (one-third of the component weight); and
- good standard of living, as indicated by the GDP.

Before calculating HDI, the indicator of each aforementioned component has to be determined, and then the HDI is calculated, which is a simple average of the three component indicators. The first UNDP report on human development was presented in 1990 for the sole goal of placing humans in the centre of the developmental process when there are economic debates, the policy is being formed, and a propagating work is performed. Each report is dedicated to the significantly relevant development discussion topic and presents an innovative analysis together with policy recommendations.

In order to make decisions on a global, country, or regional scale, policy measure analysis methods are applied, whereas local assessment methods are applied on a project scale.

In the context of sustainability assessment, integrated methods of assessment are mostly *ex ante* methods that are applied in the form of possible scenario analysis. Many of these integrated assessment means rely on system analysis and involve aspects of nature and society (Gough et al. 1998). Integrated assessments consist of many different means. Integrated environmental problem assessments are performed by using such means as multi-criteria analysis, risk analysis, vulnerability analysis, and cost/benefit analysis.

2.4.2 Conceptual Framework and System Dynamics

Conceptual framework analyses quantitative (causative) relations and applies flow diagrams, flow maps, etc. A conceptual framework can be applied in order to visualise and determine changes in the system, which positively impact sustainability, or to apply powerful computerised models for relation conceptualisation. System dynamics is the creation of computerised models to depict complex systems and experiment with them as well as monitor the long-term operation of these models and analyse various possible scenarios. General and partial balance models are an example of models applied for sustainability assessment: GEMINI, RAINS, TIMES, BALANCE, etc. IMAGE model is meant for monitoring and analysing social, biosphere, and climate system dynamics.

2.4.3 Multi-Criteria Analysis

Multi-criteria analysis is applied to assess the impact of a project or policy means based on opposing criteria. Multi-criteria analysis sets targets and tasks and seeks to weigh them and set an optimal policy tool based on all targets and tasks. This method allows rating both quantitative and qualitative data. This methodology was used to select the policy for energy and environment (Greening and Bernow 2004).

2.4.4 Vulnerability Analysis

Vulnerability analysis assesses the vulnerability of human–natural system in order to determine how sensitive a system is to changes and how it is able to deal with those changes. If it is determined that a human system or a natural system is vulnerable, a risk analysis is performed. Vulnerability analysis was performed on society and ecosystems while studying the impact of climate change (Kann and Weyant 2000).

Having analysed the sustainability assessment methods based on their ability to integrate nature and society and involve long-term periods and different area levels, it can be stated that only some of them integrate nature and society or all three dimensions of sustainability. As seen from the provided grouping of methods, only integrated methods and methods of sustainable development involve all sustainable development dimensions. Many methods involve only the environmental dimensions, especially on a product scale. Only the life-cycle costs assessment involves economic and environmental costs of the product.

In order to expand the analysis, it is aimed to integrate or join sustainable development assessment methods. For example, *life-cycle assessment* (environmental impact assessment method) was joined with *life-cycle costs assessment* (economic method) and *social life-cycle assessment*. Even though many methods involve the national level, they can also be applied at lower levels. Product level sustainability assessment methods are not related to the location; however, the efforts are made to improve these means, in order to bind them with the influence in a particular area. Forecasting methods are useful to determine the impact on sustainability on a long-term perspective. Sustainability assessment methods should be more standardised and provide more transparent results because the abundance and variety of the latter provide much confusion when rating the sustainability of policy means, projects, or products and choosing from alternative options.

In order to select proper climate change mitigation means in the energy sector, it is very important that they would be able to ensure other energy policy goals as well. Sustainability assessment of climate change mitigation means or the impact of climate change mitigation policy means on the assessment of sustainable development indicators plays an important role here.

For the purpose of comparing climate change mitigation means, the integrated indicator based on the sustainable energy development indicator system could be calculated; however, multi-criteria decision-making models allow maintaining the principle of interconnectedness among sustainable energy development indicator systems, while the calculation of integrated sustainable development indicators is the sum of the deviation of sustainable energy development indicators from the average.

Chapter 7

Designing for Sustainability

7.1 Objectives

Sustainability should be viewed as a common sense ingredient of design. However, other performance requirements and budget concerns can frequently override design decisions made to improve sustainability. Now, the ownership costs and availability requirements of increasingly complex modern systems and equipment demand that designing for sustainability is as important as designing for other performance characteristics. The design engineer must ensure that considerations for sustainability are an integral element of every design trade study or design change activity.

The basic objectives of designing for sustainability are to meet the operational readiness requirements for the product and to reduce support costs. A design engineer committed to these objectives will continually challenge the design to uncover weaknesses and potential sustainability problems. The objective is to design-in sustainability. If this objective is not met and the product fails to meet sustainability objectives, corrective design changes will have to be made later in the product's life cycle at significant expense. The primary objective of a sustainability program is to identify and correct sustainability problems early in the design process when correction simply requires changing drawings.

7.1.1 Support Concepts

Support concepts are the methods by which the customer intends to sustain the product. They can be as varied as the design itself and range from discard at failure to a complete overhaul at failure. They may include periodic or scheduled maintenance or overhaul. They can include maintenance performed by the customer, the supplier, a third party, or some combination of the three. Within the military services, three levels of maintenance are normally defined: organizational (on-site), intermediate (local shops), and depot (an overhaul facility). Table 7.1 provides a brief description of each level of maintenance. No one definition of maintenance levels could be found for the commercial sector. However, perhaps defined somewhat differently or combined in some way, the

Table 7.1 Levels of Maintenance

Level of Maintenance	*Where Normally Performed*	*Description*
Organizational	On the product at the customer's operational or product site	Normally is limited to periodic performance checks, visual inspections, cleaning, limited servicing, adjustments, and removal and replacement of some components (i.e., constituent module, part, item, etc., of the product). Repair of removed components is normally not made at this level. Instead, the failed component is replaced with a spare. The removed component is then sent to the next level of maintenance (usually intermediate) for repair. Diagnostics, accessibility, and ease of removal and replacement are very important and should be key design considerations. At this level, the primary goals are keeping the product in a serviceable condition and rapidly restoring the product to an operable condition after failure using low-to-moderate skilled personnel.
Intermediate	On the product or a repairable component of the product at a customer's "shop location"	Products might be repaired by removal and replacement of parts or modules, or the parts or modules of a product might be repaired. The skill level of personnel is usually higher than at the organizational level of maintenance. Intermediate level of repair facilities may also be tasked with doing limited depot/overhaul level repairs. These types of repairs are typically based upon technical knowledge, facilities, and potential cost savings.
Depot	On the product or a repairable component of the product at a specialized repair facility operated by the customer or the original equipment manufacturer (OEM)	Facility may very well be structured like an assembly line. Maintenance includes rebuilding or overhauling a product and may be performed on a specific lot of failed equipment that has been screened for similarity in failure type. The most highly skilled and trained technical personnel are assigned to depots. Test equipment is very complex, technical publications are more detailed, and manufacturing source data are frequently available. One specific depot might be structured to support all forms of communication radios or all types of pumps.

same levels of maintenance are considered representative of those used by commercial industry. Maintenance performed at these levels keeps the product serviceable or restores it to an operational condition after a failure.

Maintenance can include two basic types of tasks. The first, called preventive maintenance (M_P), is usually performed at the organizational level. M_P retains a product in serviceable condition by inspections, servicing, and other preventive measures performed on a calendar, cyclical, or performance trending basis. The second is corrective maintenance (M_C). M_C is performed to return a product to operation after a failure and may be accomplished at the operational, intermediate, or depot level. The cost of maintenance, preventive or corrective, is directly determined by the maintenance of the design.

A support concept is more than simply identifying whether M_P and M_C are required and whether maintenance will be performed at one, two, or three levels of organization. It means deciding on a run-to-failure or on-condition maintenance approach. It also addresses who will provide support: the customer, the product manufacturer, or both. Often, the military services elect to plan for contractor support at the intermediate and depot levels until a product has been proven in actual use. Then responsibility for the maintenance may be transitioned to the military service. Such a strategy is called interim contractor support. Finally, a support concept can involve centralizing some organizational and intermediate level maintenance at one or two sites.

The approach to handling ambiguity groups is also a part of the support concept. Sometimes, factors make FI to a single replaceable unit (RU) or item impossible to achieve. These factors include the complexity that would be added by fault isolating to a single item, the total cost associated with fault isolating to a single item compared with the cost associated with fault isolating to two or more items, and the type of technology being used. Consequently, some failures will be detected by the integrated diagnostics and isolated to two or more items. To correct the failure, one of two basic approaches may be used. For relatively small ambiguity groups, the entire group will be replaced. For larger groups, items in the group will be iteratively replaced until the failure is corrected. The decision to use group or iterative replacement is primarily based on economics and the effect on predicted total DT.

A product may be a new development, a nondevelopmental item, or a COTS item. As shown in Table 7.2, the latitude that planners have in selecting a support concept is determined by the amount of new development involved.

For new development products, the support concept can and should greatly influence the design for maintenance. For example, ease of disassembly is not a concern for nonrepairable products that are discarded after failure. But if the product is a component or subsystem of a larger

Table 7.2 Latitude in Selecting a Support Concept

Type of Product	*Degree of Latitude*
New development	High—the designers can respond to the chosen concept as they design the product.
Nondevelopmental items	Less than for new development.
COTS	Little to none. It is unlikely that the engineering, design, and other detailed data needed to develop an organic repair capability will be available. Also, the supplier (OEM) will most likely sustain configuration control below the product level, not the customer. So, support for COTS will often consist only of removal and replacement at the operational level with depot and even intermediate maintenance usually performed by the OEM.

product, accessibility to facilitate removal and replacement is important. If a two-level maintenance (2LM) concept is desired, then reliable diagnostics are essential. If the diagnostics are not reliable, then items will be removed and shipped all the way to a depot, which may then determine that the item is good and place it back in the supply chain. Not only are many assets tied up in this situation but also it will take considerably longer to uncover the root cause of field problems. Finally, the design approach for a product can be very different depending on whether the customer or the contractor will be providing the support.

7.1.2 Operational and Support Environment

A supplier must understand the environment in which the customer will operate and sustain the product. Environmental factors, such as temperature and humidity, limit the way in which personnel can perform maintenance. For example, when maintaining products in very cold climates or under hazardous conditions (radioactive, biological, or chemical environments) personnel must wear heavy clothing and gloves. Such clothing restricts movement, requires more room for access, and reduces dexterity. In addition, materials can shrink or expand making it difficult to connect and disconnect mating parts. In hot climates with high humidity, perspiration can impair vision and affect a person's grip. If maintenance must be performed outside, the maintenance engineer must try to design access panels so that rain cannot penetrate into the interior of a product. Also, it might be necessary to perform maintenance during product operation. If so, the maintenance engineer's primary concern is to design the product and procedures to minimize the hazards involved with maintenance.

In addition to analytical techniques, the maintenance engineer has two excellent methods of characterizing the support environment. First, the customer's maintenance personnel can be brought in to participate in the design process at the earliest phase of product development. Second, maintenance and design engineers can visit the customer's operating sites to gain first-hand knowledge of the operational and support environment. Every product needs to be assessed for the environmental impact on maintenance.

7.1.3 Preventive versus Corrective Maintenance Requirements

M_P is usually self-imposed DT (although it may be possible to perform some M_P while the product is operating). M_P consists of actions intended to prolong the operational life of the equipment and keep the product safe to operate. Ideally, a product will require no servicing or other M_P and either the probability of failure is remote or redundancy makes failure acceptable (however, one often-required M_P task is to verify the operational status of redundant components prior to a mission). For such an ideal product, only M_C, if any, would be required. Most often, however, failure is not a remote possibility. Moreover, most products of any complexity require some servicing, even if that only consists of cleaning. Sometimes failures can actually be prevented by M_P. The goal, then, is to identify only the M_P that is absolutely necessary and cost-effective.

Figure 7.1 illustrates the two major categories of maintenance, M_P and M_C, and the tasks associated with each.

M_P is only applicable if the probability of failure is reduced by the M_P, or there is a quantitative indication of an impending failure. In the case of the former criterion, M_P has no benefit for items that have a random pattern of failure (i.e., constant failure rate [FR]). Consequently, we rarely, if ever, will use a M_P action for electronics since electronics exhibit a random pattern of failures. Mechanical items, on the other hand, usually have a limited useful period of life and then begin to wear out.

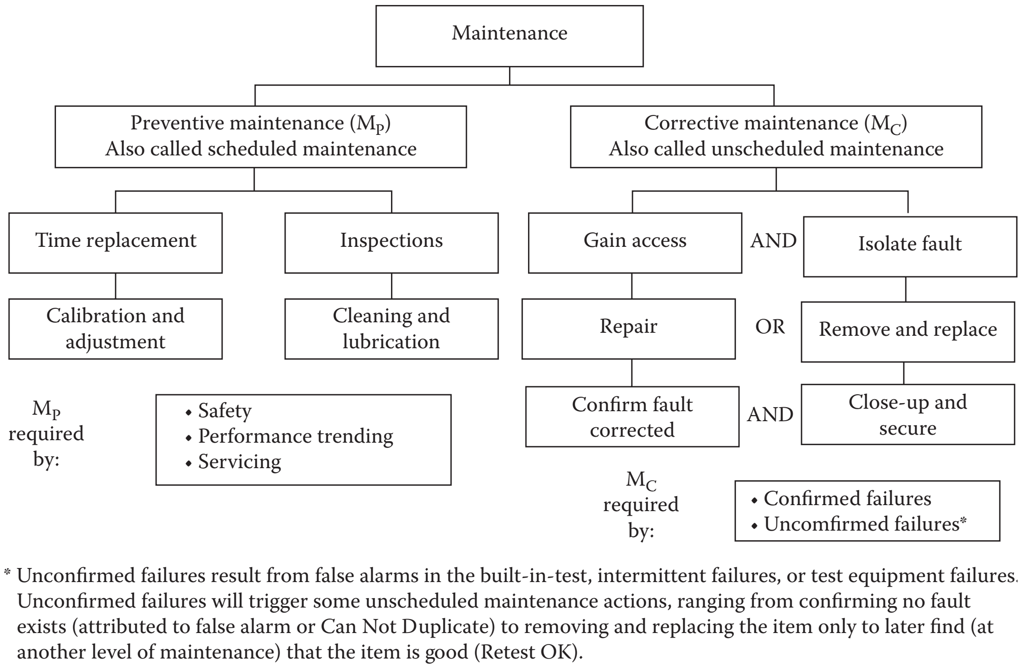

Figure 7.1 Major categories of maintenance.

The second criterion for determining if M_P is applicable is whether or not there is a quantitative indication of an impending failure (functional failure). If reduced resistance to failure can be detected (potential failure) and there is a consistent time between potential failure and functional failure, then M_P is applicable. Performance trending, as discussed in the Reliability chapter, has long been used to monitor operating parameters that have been shown to be dependable predictors of an impending failure. M_P may be applicable but it must also be effective. That is, it must

- Reduce the FR to an acceptable level
- Be less expensive than M_C and the cost of failure without M_P

7.1.4 Two-Level Maintenance

The objective of 2LM is to reduce manpower, equipment, facilities, and mobility footprint while still meeting the Air Force's Global Engagement mission objectives. The approach for meeting this objective is to modify or eliminate the intermediate (off-equipment) function when possible and consolidate that repair function at a depot or regional level.

Using state-of-the-art communications, item visibility, and fast transportation systems, unserviceable parts will be moved rapidly to and through the regional, depot, or contractor repair processes. 2LM will be performed at the appropriate organic Air Force regional, depot, or contractor repair activity. A regional repair center is a hybrid of three-level maintenance (3LM) and 2LM and combines the intermediate level maintenance function from multiple bases at one location. Therefore, from the perspective of the affected bases, the unserviceable assets are treated as 2LM and shipped to the regional repair center. The regional repair center performs the traditional intermediate level maintenance and the depot continues to perform the same type of repairs under the 3LM concept. This regional repair center concept should be applied where it makes good economic sense as it offers similar advantages to that of 2LM. Some of these advantages are

- Consolidates like-maintenance efforts
- Affords a mobility/surge option
- Provides a second source and/or multiple sources of repair
- Provides a source of experienced personnel
- Allows for increased repair flexibility while maintaining lower overall repair costs due to economies of scale

Good reliability performance is a desired attribute of a 2LM candidate. Good reliability indicates that a 2LM concept for the asset would not significantly increase transportation costs or depot workload. Good maintenance, specifically good diagnostics, is also important. Good diagnostics have a low CND rate. CND is an indicator of the frequency at which an asset appears to have failed on a weapon system or equipment end item when that failure cannot be duplicated in the repair shop. In such cases, the asset is returned to the supply system. A high CND rate would mean additional transportation costs and increased demand on the supply and repair systems in a pure two-level repair environment where all base level repair capability has been eliminated. Thus, a low CND rate is important in a 2LM environment.

7.2 Human Engineering

7.2.1 Human Factors

Human factors is an important design consideration. Often a specialist, a human engineering (HE) engineer, addresses the human factors element of design. The HE engineer has two roles. First, the HE engineer represents the potential user, operator, and sustainer and is concerned with ease of operation, safety, comfort, workloads, and so on. Second, the HE engineer evaluates people as "components" and their contribution to product effectiveness. The HE engineer is concerned with many design issues including:

- Safety of operators and sustainers
- Which functions to allocate to humans
- How best to present information to the user, operator, or sustainer
- Accessibility
- The design of tools and controls
- Anthropometry
- Required skill levels

A key focus of the HE engineer is on presenting information to operators and maintainers. Although information is usually presented through visual displays and auditory signals, other methods include touch, smell, the sense of balance (vestibular sense), or sensations of position and movement (kinesthesis). Each method has its own variables. Visual displays, for example, can be in color or black and white, use symbols or text, use moving scales with fixed indicators or fixed scales with moving indicators, and so on. Selecting the best method requires an understanding of how humans process, interpret, and store information; the detection and differential sensitivity of the human senses; and human psychology and physiology. Figure 7.2 illustrates some of the factors involved in human information processing.

The maintenance, HE, reliability, safety, and other design engineers must develop a product design that contributes to proper operator responses by creating perceivable and interpretable stimuli requiring reactions within the user's, operator's, or sustainer's capabilities. Feedback ought to be incorporated into the design to verify that operator responses are correct. In other words, product characteristics should serve as both input and feedback stimuli to the operator or sustainer. These interactions between the human and the product are depicted in Figure 7.3.

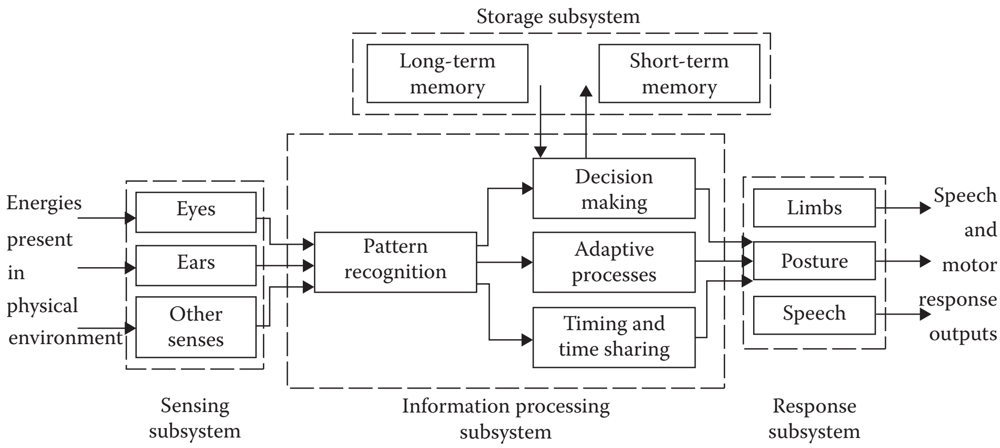

Figure 7.2 The human information processing system.

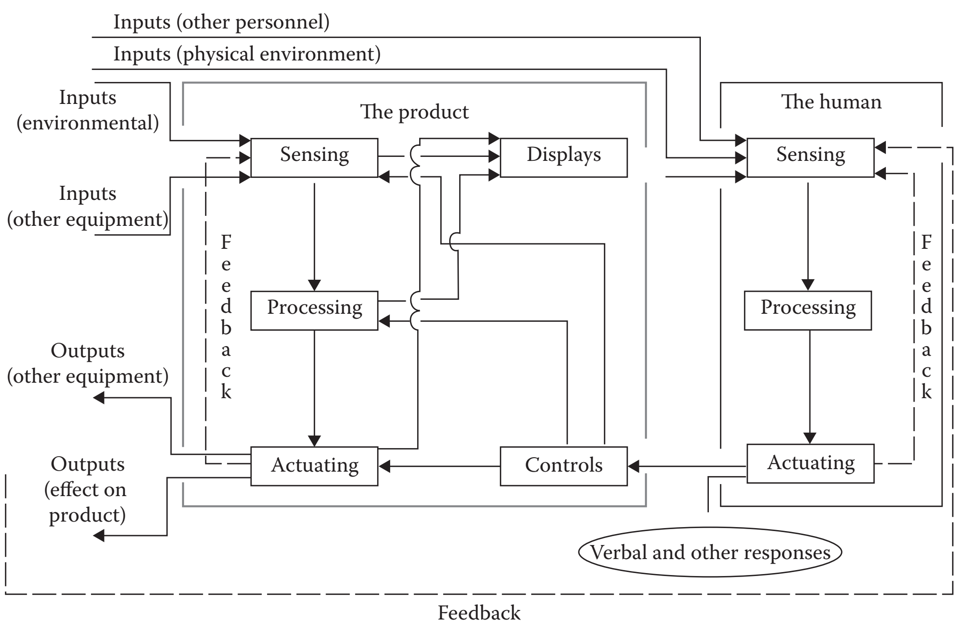

Figure 7.3 Interactions between human and product.

Humans control the functions of a product with switches, knobs, levers, wheels, and other devices. Collectively, such devices are called controls. In selecting the proper control for a specific function, the HE engineer must evaluate the function of the control, the requirements of the control task, the informational needs of the human, the requirements imposed by the work environment, and the consequences of inadvertent or accidental operation of the control.

Anthropometry is the science of measuring various human physical characteristics, primarily size, mobility, and strength. Using such measurements in designing a product, workplace, support equipment, and clothing, designers can enhance the efficiency, safety, and comfort of users, operators, and sustainers. People vary in size and strength within any group. This variance can be expressed statistically by taking appropriate measurements of the population and calculating the mean and standard deviation. Based on these statistics, percentiles can be calculated. For example, a 90th percentile height for American men means that only 10% of the males in the United States are taller than that height. Normally, the HE and maintenance engineer will design for people who are in the 95th or higher percentile for weight, stature, sitting height, and other anthropometric measurements. Anthropometric tables and charts are available in HE handbooks and military standards to help the engineer assess human physical interface factors. These tables and charts include information on percentile measurements of physical size; allowances for clothing; maximum strength (static forces and torque) of hands, fingers, and legs; and range of motion.

7.3 Tools and Support Equipment

Few products can be sustained without using some tools and support equipment. Maintenance of many consumer products requires only common hand tools, such as screwdrivers and pliers. Maintenance of other products can require test equipment, servicing stands, protective clothing, specialized tools, and so on. It is the sustainability engineer's responsibility to identify the tools and equipment needed by maintenance personnel to support the product.

To keep costs down and reduce the amount of specialized training required, the maintenance engineer should try to use tools and equipment already in use for other products. For example, airlines have a large investment in hand tools, support equipment, and other items with which aircraft are sustained. A commercial aircraft manufacturer who ignores this "in-place" inventory and designs an aircraft requiring all new tools and equipment will find it difficult to market a new aircraft, no matter how advanced it may be.

During design, the engineer must often deal with human factors considerations and this is especially important in the design of tools. Even the simplest of hand tools should be designed with a regard for the human form, manual dexterity, and other human factors. If they are not, they will be more difficult to use, will tire the user more quickly, and can result in injury or accidents. In the commercial marketplace, a variety of screwdrivers featuring new designs for the handle have been introduced. These new designs are intended to make gripping the screwdriver more natural with less chance of injury to the tendons and muscles of the hand and wrist.

Special tools, those not commonly found in the toolboxes of people who sustain a given product, should be avoided if at all possible. Using standard tools has been shown to minimize the possibility of damage or injury and the time associated with connecting and disconnecting items. In addition, special tools increase the cost of supporting the product during its useful life.

Support equipment includes diagnostic equipment (e.g., automatic test equipment [ATE]), dollies and lifting devices, stands and jacks, air conditioners and heaters, work lights, ladders and lifts, towing vehicles and tow bars, and other equipment needed to support the product. As is the case with tools, it is usually advisable to design the product to be supported with support equipment already used by those who will sustain the product. By using "standard" support equipment, costs and training requirements are reduced.

When newly designed tools and support equipment are needed, virtual reality (VR) techniques can be used to evaluate virtual "copies" of the support equipment or tool by "performing" maintenance activities with them. VR could allow technicians to view virtual information panels "superimposed" (using augmented reality techniques) on the actual equipment. Also, the support concept and any customer constraints or requirements regarding support equipment and tools must be understood and considered during all design trade-offs and analyses.

In designing new tools and support equipment, anthropometric measurements should be used to enhance the efficiency, safety, and comfort of users, operators, and sustainers. In addition, early estimates of maintenance time, labor hours, and other maintenance metrics can be used in making preliminary assessments of the support equipment and tools.

Finally, it is important to note that maintenance should be as much a consideration for the support equipment as it is for the product itself. Maintenance affects the availability and support costs of both the support equipment and the product. So in designing or selecting off-the-shelf support equipment, maintenance criteria should be part of requirements for the support equipment.

7.4 Maintenance Training

At the turn of the twentieth century, maintenance training was accomplished in large measure through apprenticeships, essentially on-the-job training (OJT). One learned how to do a task by watching and learning from an experienced person, a mentor. Most maintenance tasks were simple by today's standards and did not require a sophisticated or technical education. As products increased in complexity, incorporating ever more sophisticated technology, it became clear that OJT alone was insufficient. Classroom training and more stringent educational requirements quickly became commonplace in maintenance training, and in training in general. The training of maintenance personnel is now extremely important, expensive, and time-consuming. Many methods of training are now available and are often used in combination as part of a comprehensive training program. Table 7.3 lists some of the methods used to train maintenance personnel.

Traditionally, training focuses on

- Addressing performance deficiencies
- Individual skills and knowledge
- Improving the job–person fit

Selecting the most appropriate training method is critical. Trying to teach a manual skill through lecture, for example, will not produce very good results. At the other extreme, the theory of operation of a product does not lend itself to teaching by demonstration. Table 7.4 provides some prerequisites for selecting training methods for any training activity and some guidelines to follow in the selection process.

In designing the product, the engineer can and must consider the impact on training.

Table 7.3 Maintenance Training Methods

Method	*Comments*
• On-the-job	• Perhaps the oldest method of learning a trade or an activity requiring manual dexterity and skill • Time-consuming and requires skilled, experienced mentor
• Classroom	• Can include demonstration by the trainer with observation and imitation by the trainee, lectures • Best suited to theory and intellectual content
• Simulation	• Use of VR[a] and other simulation methods • Provides realistic "hands-on" experience in a controlled environment
• Computer aided	• Basically another form of classroom training in which the class size is one and the instructor's knowledge has been captured in software • A self-study approach • Allows self-paced learning
• Distance learning	• Can be used to deliver classroom training and self-study programs

[a]*Maintenance and manufacturing procedures, especially procedures that are seldom performed or are difficult to teach using conventional approaches, can be taught using VR. VR could also be used to train individuals in performing hazardous procedures, disposing of hazardous materials, or performing life-threatening procedures.*

Table 7.4 Selecting a Training Method

Prerequisites	*Guidelines*
• Set training objectives • Set training priorities • Design a curriculum	• Choose training methods suited to the training objective and material • Combine principles of andragogy (the art and science of helping adults learn) with a variety of teaching methods that allow for optimal training • Determine which training methods are most familiar to the trainees • Review the training activity objectives to make sure the training method is appropriate for achieving the objectives

Specific questions that can be asked of a design alternative are

- Does the design incorporate diagnostic resources at each level of maintenance that reduce the need for training?
- Does the design make use of tools and equipment already in use for other products thereby eliminating or reducing the amount of specialized training required?
- Does the design enhance standardization thereby helping to reduce training requirements both in number of personnel and the level of skill required?
- Can the planned maintenance personnel sustain the design using their existing skills?
- Is special training equipment req.uired?

7.5 Testability and Diagnostics

Testability is an inherent design characteristic, whereas diagnostics involves additional factors. Attention paid to both in design will reduce not only the cost of producing a product but certainly the cost of maintaining the fielded product. BIT is one typical approach to diagnostics and one that reduces maintenance labor and external test equipment. It is an important diagnostic tool and considering it at all levels of design is important for two reasons. First, densely packaged devices are increasingly used in the circuit card design. They decrease the accessibility required for and increase the risks of guided-probe testing. So including BIT in such designs is critical to effective diagnostics. Second, many integrated circuit vendors are incorporating some form of BIT into their designs. Designers must capitalize on this fact for higher-level designs (e.g., board or module) that use such devices by integrating lower-level BIT capabilities with higher-level BIT designs. Doing so increases the vertical testability of the system; that is, allows BIT tests performed at higher support levels (e.g., factory) to be used at lower levels (e.g., field). This characteristic will help sustain consistency across maintenance levels and may reduce the numbers of RTOKs or CNDs.

As is the case with many design approaches, the use of BIT is a matter of trade-offs. For example, as the coverage of BIT is increased, the chance for false alarms also increases, possibly increasing the demand for maintenance. The most important factor in BIT design is early planning. Without planning for BIT early in the life cycle, it will be harder to maximize any advantages offered by the use of BIT while minimizing any negative impacts such as increased design cost, higher hardware overhead, and increased FR. In one study, "Chip-To-System Testability," for Rome Laboratory (DoD 1997), Research Triangle Institute and Self-Test Services gave the following five axioms that allow designers to capitalize on BIT.

- Plan for BIT starting at the earliest stage of the program
- Design BIT in conjunction with the functional design, not as an afterthought
- Use the same high degree of engineering cleverness and rigor for BIT that is used for the functional design
- Use computer-aided design tools to design BIT whenever possible
- Incorporate the subject of BIT into peer, design, and program reviews

7.5.1 Testability

Testability is a subset of maintenance. However, because of the negative impact of poor testability on production and maintenance costs, testability is recognized as a separate design discipline in its own right and will continue to be treated as such, at least in the foreseeable future. Therefore, it is important to develop a testability program plan as an integral part of the systems engineering process and to elevate testability to the same level of importance accorded to other product assurance disciplines. Plans must include the requirement to analyze a design to ensure it provides for efficient and effective fault detection and isolation (FD&FI).

Ensuring that a product is testable requires adherence to some basic testability design principles. A list of the most common testability design principles, along with a brief description of each, is shown in Table 7.5. In addition to the principles shown in the table, checklists of testability design practices have been developed that are specific to technologies, such as analog, digital, mechanical, and so on. A detailed checklist is provided in Table 7.6.

Determining the amount of testability necessary in a design will be driven by the requirements for FD&FI. FD requirements are typically stated as the percentage of all possible faults that can be detected, using defined means (BIT, semiautomatic/automatic test, etc.). For instance, a system may have a requirement of 95% FD, indicating that 95% of all possible failures are to be detectable by the diagnostic capability of the system. FI requirements are typically stated as the percentage of time that FI is possible to a specified number of components. As an example, a system may have a requirement of 90% isolation to a single RU, 95% isolation to an ambiguity group of two or fewer RUs, and 100% isolation to an ambiguity group of three or fewer RUs. Table 7.7 lists some common measures of testability.

Table 7.5 Testability Design Principles

Principle	*Description*
Physical and functional partitioning	The ease or difficulty of FI depends to a large extent upon the size and complexity of the units that are replaceable. Partitioning the design such that components are grouped by function (i.e., each function is implemented on a single RU) or by technology (e.g., analog, digital) whenever possible will enhance the ability to isolate failures.
Electrical partitioning	Whenever possible, a block of circuitry being tested should be isolated from circuitry not being tested via blocking gates, tri-state devices, relays, and so on.
Initialization	The design should allow an item to be initialized to a known state so it will respond in a consistent manner for multiple testing of a given failure.
Controllability	The design should allow external control of internal component operation for the purpose of FD&FI. Special attention should be given to independent control of clock signals, the ability to control and breakup feedback loops, and tri-stating components for isolation.
Observability	Sufficient access to test points, data paths, and internal circuitry should be provided to allow the test system (machine or human) to gather sufficient signature data for FD&FI.
Test system compatibility	Each item to be tested should be designed to be electrically and mechanically compatible with selected or available test equipment to eliminate or reduce the need for a large number of ID designs.

Table 7.6 Inherent Testability Checklist

Mechanical design checklist (for electronic designs)		
• Is a standard grid layout used on boards to facilitate identification of components? • Is the number of I/O pins in an edge connector or cable connector compatible with the I/O capabilities of the selected test equipment? • Are connector pins arranged such that the shorting of physically adjacent pins will cause minimum damage? • Is each hardware component clearly labeled?	• Is spacing between components sufficient to allow for clips/test probes? • Has provision been made to incorporate a test header connector into the design to enhance ATE testing of surface-mounted devices? • Is defeatable keying used on each board so as to reduce the number of unique interface adapters required? • Is the design free of special setup requirements that would slow testing?	• Are all components oriented in the same direction (pin 1 always in same position)? • Does the board layout support guided-probe testing techniques? • When possible, are power and ground included in the I/O connector or test connector? • Have test and repair requirements impacted decisions on conformal coating? • Does the item warm up in a reasonable amount of time?
Partitioning checklist (for electronic functions)		
• Is each function to be tested placed wholly upon one board? • Within a function, is the size of each block of circuitry to be tested small enough for economical FD&FI? • Is the number of power supplies required compatible with the test equipment?	• If more than one function is place on a board, can each be tested independently? • If required, are pull-up resistors located on same board as the driving component? • Is the number and type of stimuli required compatible with the test equipment?	• Within a function, can complex digital and analog circuitry be tested independently? • Are analog circuits partitioned by frequency to ease tester compatibility? • Are elements included in an ambiguity group placed in the same package?
Test control checklist		
• Are connector pins not needed for operation used to provide test stimulus and control from the tester to internal nodes?	• Can circuitry be quickly and easily driven to a known initial state (master clear, less than N clocks for initialization sequence)?	• Are redundant elements in design capable of being independently tested?

(*Continued*)

Table 7.6 Inherent Testability Checklist (*Continued*)

Test control checklist		
• Is it possible to disable on-board oscillators and drive all logic using a tester clock? • Is circuitry provided to bypass any (unavoidable) one-shot circuitry? • In microprocessor-based systems, does the tester have access to the data bus, address bus, and important control lines? • Are input buffers provided for those control point signals with high drive capability requirements?	• Can long counter chains be broken into smaller segments in test mode with each segment under tester control? • Can feedback loops be broken under control of the tester? • Are active components, such as demultiplexers and shift registers, used to allow the tester to control necessary internal nodes using available input pins?	• Can the tester electrically partition the item into smaller independent, easy-to-test segments (placing tri-state element in a high impedance state)? • Have provisions been made to test the system bus as a stand-alone entity? • Are test control points included at those nodes which have high fan-in (test bottlenecks)?
Parts selection checklist		
• Is the number of different part types the minimum possible? • Is a single logic family being used? If not, is a common signal level used for interconnections?	• Have parts been selected that are well characterized in terms of failure modes?	• Are the parts independent of refresh requirements? If not, are dynamic devices supported by sufficient clocking during testing?
Test access		
• Are unused connector pins used to provide additional internal node data to the tester? • Are test access points placed at those nodes that have high fan-out? • Are active components, such as multiplexers and shift registers, used to make necessary internal node test data available to the tester over available output pins?	• Are signal lines and test points designed to drive the capacitive loading represented by the test equipment? • Are buffers employed when the test point is a latch and susceptible to reflections? • Are all high voltages scaled down within the item prior to providing test point access so as to be consistent with tester capabilities?	• Are test points provided such that the tester can monitor and synchronize to on-board clock circuits? • Are buffers or divider circuits employed to protect those test points that may be damaged by an inadvertent short circuit? • Is the measurement accuracy of the test equipment adequate compared to the tolerance requirement of the item being tested?

Table 7.6 Inherent Testability Checklist (*Continued*)

Analog design checklist		
• Is one test point per discrete active stage brought out to the connector? • Are circuits functionally complete without bias networks or loads on some other unit under test (UUT)? • Is a minimum number of complex modulation or unique timing patterns required? • Are response rise time or pulse width measurements compatible with test capabilities? • Are standard types of connectors used?	• Is each test point adequately buffered or isolated from the main signal path? • Is a minimum number of multiple phase-related or timing-related stimuli required? • Are stimulus frequencies compatible with tester capabilities? • Are stimulus amplitude requirements within the capability of the test equipment? • Does the design avoid external feedback loops?	• Are multiple, interactive adjustments prohibited for production items? • Is a minimum number of phase or timing measurements required? • Does the design allow testing without heat sinks? • Do response measurements involve frequencies compatible with tester capabilities? • Does the design avoid or compensate for temperature-sensitive components?
Radio frequency (RF) design checklist		
• Do transmitter outputs have directional couplers or similar signal sensing/attenuation techniques employed for BIT, off-line test monitoring purposes, or both? • Has provision been made in the off-line ATE to provide switching of all RF stimulus and response signals required to test the subject RF UUT? • Are the RF test I/O access ports of the UUT mechanically compatible with the off-line ATE I/O ports?	• If an RF transmitter is to be tested utilizing off-line ATE, has suitable test fixturing (anechoic chamber) been designed to safely test the subject item over its specified performance range of frequency and power? • Does the off-line ATE or BIT diagnostic software provide for compensation of UUT output power and adjustment of input power so that RF switching and cable errors are compensated for in the measurement data?	• Have suitable termination devices been employed in the off-line ATE or BIT circuitry to accurately emulate the loading requirements for all RF signals to be tested? • Does the RF UUT employ signal frequencies or power levels in excess of the core ATE stimulus/ measurement capability? If so, are signal converters employed within the ATE to render the ATE/UUT compatible?

(*Continued*)

Table 7.6 Inherent Testability Checklist (*Continued*)

Radio frequency (RF) design checklist		
• Have all RF testing parameters and quantitative requirements for these parameters been explicitly stated at the RF UUT interface for each RF stimulus/response signal to be tested?	• Have adequate testability (controllability/ observability) provisions for calibrating the UUT been provided? • Has the UUT/ATE RF interface been designed so that the system operator can quickly and easily connect and disconnect the UUT without special tooling?	• Have RF compensation procedures and databases been established to provide calibration of all stimulus signals to be applied and all response signals to be measured by BIT or off-line ATE to the RF UUT interface? • Has the RF UUT been designed so that repair or replacement of any assembly or subassembly can be accomplished without major disassembly of the unit?
Electro-optical design checklist		
• Do all buses have a default value when unselected? • Have optical splitters/ couplers been incorporated to provide signal accessibility without major disassembly? • Has temperature stability been incorporated into fixture/UUT design to assure consistent performance over a normal range of operating environments? • Can requirements for bore-sighting be automated or eliminated? • Do monitors possess sufficient sensitivity to accommodate a wide range of intensities?	• Does the design contain only synchronous logic? • Have optical systems been functionally allocated so that they and associated drive electronics can be independently tested? • Are the ATE system, light sources, and monitoring systems of sufficient wavelength to allow operation over a wide range of UUTs? • Has adequate filtering been incorporated to provide required light attenuation? • Can all modulation models be simulated, stimulated, and monitored? • Do optical elements possess sufficient range of motion to meet a variety of test applications?	• Do light sources provide enough dynamics over the operating range? • Does the test fixturing intended for the off-line test present the required mechanical stability? • Is there sufficient mechanical stability and controllability to obtain accurate optical registration? • Can targets be automatically controlled for focus and aperture presentation? • Are optical collimators adjustable over their range of motion via automation? • Are all memory elements clocked by a derivative of the master clock? (Avoid elements clocked by data from other elements.)

Table 7.6 Inherent Testability Checklist (*Continued*)

Electro-optical design checklist		
• Can optical elements be accessed without major disassembly or realignment? • Do test routines and internal memories test pixels for shades of gray?		• Are all clocks of differing phases and frequencies derived from a single master clock?
Digital design checklist		
• Does the design avoid resistance capacitance one-shots and dependence upon logic delays to generate timing pulses? • Is the design free of wired OR logic? • Will the selection of an unused address result in a well-defined error state? • Is the number of fan-outs for each internal circuit limited to a predetermined value? • Is the number of fan-outs for each board output limited to a predetermined value?	• Are latches provided at the inputs to a board in those cases where tester input skew could be a problem? • For multilayer boards, is the layout of each major bus such that current probes or other techniques may be used for FI beyond the node? • Does the design support testing of "bit slices"?	• Does the design include data wrap-around circuitry at major interfaces? • Is a known output defined for every word in a read-only memory (ROM)? • Are sockets provided for microprocessors and other complex components? • If the design incorporates a structured testability design technique (scan path, signature analysis), are all the design rules satisfied?
BIT checklist		
• Can BIT in each item be exercised under control of the test equipment? • Does the BIT use a building-block approach (all inputs to a function are verified before that function is tested)? • Does on-board ROM contain self-test routines?	• Is the test program set designed to take advantage of BIT capabilities? • Does building-block BIT make maximum use of mission circuitry? • Is the self-test circuitry designed to be testable? • Is the predicted FR contribution of the BIT circuitry within stated constraints?	• Are on-board BIT indicators used for important functions? Are BIT indicators designed such that a BIT failure will give a "fail" indication? • Is BIT optimally allocated in hardware, software, and firmware? • Have means been established to identify whether hardware or software has caused a failure indication?

(*Continued*)

Table 7.6 Inherent Testability Checklist (*Continued*)

BIT checklist		
• Does BIT include a method of saving on-line test data for the analysis of intermittent failures and operational failures that are nonrepeatable in the maintenance environment? • Is the additional volume due to BIT within stated constraints? • Does the allocation of BIT capability to each item reflect the relative FR of the items and the criticality of the items' functions? • Are the data provided by BIT tailored to the differing needs of the system operator and the system sustainer? • Does mission software include sufficient hardware error detection capability?	• Is the additional power consumption due to BIT within stated constraints? • Are BIT threshold values, which may require changing as a result of operational experience, incorporated in software, or easily modified firmware? • Is processing or filtering of BIT sensor data performed to minimize BIT false alarms? • Is the failure latency associated with a particular implementation of BIT consistent with the criticality of the function being monitored?	• Is the additional weight due to BIT within stated constraints? • Is the additional part count due to BIT within stated constraints? • Is sufficient memory allocated for confidence tests and diagnostic software? • Are BIT threshold limits for each parameter determined as a result of considering each parameter's distribution statistics, the BIT measurement error, and the optimum FD/false alarm characteristics?
Performance monitoring checklist		
• Have critical functions been identified (by failure mode effects and criticality analysis [FMECA]) that require monitoring for the system operation and users?	• Has the displayed output of the monitoring system received a HE analysis to ensure that the user is supplied with the required information in the best useable form?	• Have interface standards been established that ensure the electronic transmission of data from monitored systems is compatible with centralized monitors?
Diagnostic capability integration		
• Have vertical testability concepts been established, employed, and documented?	• Has a means been established to ensure compatibility of testing resources with other diagnostic resources at each level of maintenance (technical information, personnel, and training)?	• Has the diagnostic strategy (dependency charts, logic diagrams) been documented?

Table 7.6 Inherent Testability Checklist (*Continued*)

Mechanical systems condition monitoring (MSCM) checklist		
• Have MSCM and battle damage monitoring functions been integrated with other performance monitoring functions?	• Are M_P monitoring functions (oil analysis, gear box cracks) in place?	• Have scheduled maintenance procedures been established?
Sensors checklist		
• Are pressure sensors placed very close to pressure-sensing points to obtain wideband dynamic data?	• Has the selection of sensors taken into account the environmental conditions under which they will operate?	• Has the thermal lag between the test media and sensing elements been considered? • Have procedures for calibration of sensing devices been established?
Test requirements checklist		
• For each item, does the planned degree of testability support the level of repair, test mix, and degree of automation decisions?	• For each maintenance level, has a decision been made for each item on how BIT, ATE, and general purpose electronic test equipment will support FD&FI?	• Is the planned degree of test automation consistent with the capabilities of the maintenance technician? • Has a "level of repair analysis" been accomplished?
Test data checklist		
• Do state diagrams for sequential circuits identify invalid sequences and indeterminate outputs? • For computer-assisted test generation, is the available software sufficient in terms of program capacity, fault modeling, component libraries, and postprocessing of test response data? • Is the tolerance band known for each signal?	• If a computer-aided design system is used for design, does the computer-aided design database effectively support the test generation and test evaluation processes? • Are testability features included by the system designer documented in the test requirement document in terms of purpose and rationale for the benefit of the test designer?	• For large-scale integrated circuits (ICs) used in the design, are data available to accurately model the circuits and generate high-confidence tests? • Are test diagrams included for each major test? Is the diagram limited to a small number of sheets? Are inter-sheet connections clearly marked?

Table 7.7 Measures of Testability

Measure	*Description*
Fraction of faults detectable (FFD)	FFD = FD/FA, where FA = total number of actual faults occurring over time and FD = no. of actual failures correctly identified using defined means
Fraction of faults isolatable (FFI) (also called fault resolution)	$FFL_L = \frac{100}{\lambda_d} \sum_{i=1}^{N} X_i \sum_{j=1}^{M_i} \lambda_{ij}$ where: $X_i = 1$ if $M_i \le 1$; 0 otherwise N = number of unique test responses L = number of mudules isolated to (i.e., ambiguity group size) i = signature index M_i = number of modules listed in signature i j = module index within signature λ_{ij} = FR for jth module for failures having signature i λ_d = overall FR of detected failures = $\sum_{i=1}^{N} \sum_{j=1}^{M_i} \lambda_{ij}$
Fault isolation time	Derived from the MTTR. Mean fault isolation time = mean (repair time – [preparation time + disassembly time + interchange time + reassembly time + alignment time + vertification time])
False alarm rate (FAR)	FAR = number of false alarms/total number of faults detected
Maximum ambiguity group size	The largest number of items (modules, subassemblies, etc.) among which the diagnostics cannot distinguish a fault (i.e., the diagnostics can isolate the fault to this size ambiguity group but no lower)

Note that the first two measures in Table 7.7 are interrelated in that before you can isolate a fault, you must first detect it. Therefore, a testability analysis program is designed to analyze the effectiveness of the detection scheme and then to analyze the effectiveness of the isolation scheme. For complex designs, the analysis of testability often requires the use of testability design and analysis tools that provide information on FD&FI, for a given diagnostic approach, or diagnostic capability.

False alarms (in which a failure is "detected" even though none occurred) is a problem related to both testability and a system's diagnostic design. Manifesting themselves in varying degrees in avionics and other types of equipment, false alarms drain maintenance resources and reduce a system's mission readiness. CNDs and RTOKs are the two most common symptoms of false alarms.

False alarms occur for many and varied reasons, including external environmental factors (temperature, humidity, vibration, etc.), design of diagnostics, equipment degradation due to age, design tolerance factors, maintenance-induced factors (e.g., connectors, wire handling, etc.), or combinations of these factors. External environmental factors may cause failure of avionics or other equipment that do not fail under ambient conditions. These factors are believed to be a leading cause of false alarms. When the environmental conditions are removed, the "failure" cannot be found. One solution to the false alarm problem is to use a stress measurement device to record the environmental stresses before, during, and after a system anomaly.

Subsequent diagnosis can use the data to determine what occurred and whether any action (maintenance, modifications, etc.) is needed.

7.5.2 Diagnostics

Defining and developing a product's diagnostic capability depends on a number of factors such as

- The product's performance and usage requirements
- Maintenance support requirements (e.g., levels of maintenance)
- Technology available to improve diagnostics in terms of test effectiveness; reduce the need for test equipment, test manuals, personnel, training, and skill levels; and reduce cost
- The amount of testability designed into the product
- Previously known diagnostic problems on similar systems

Each factor influences the choice of an approach to detecting and isolating faults. As mentioned earlier, BIT is one approach to developing a diagnostics capability. Other approaches may include the use of automatic or semiautomatic test equipment, manual testing using bench-top test equipment, or visual inspection procedures. In nearly all cases, some combination of these approaches is needed. In all cases, trade-offs are required among system performance, cost, and test effectiveness.

Designers and managers must remember that the effectiveness of the diagnostic capability, and the cost of development, is greatly influenced by the amount of testability that has been designed into the system. A lack of test points available to external test equipment, for example, may adversely affect the ability to isolate failures to smaller ambiguity group sizes. The result is higher costs to locate the failure to a single replaceable item. The cost of test development may also increase. BIT design should be supported by the results of an FMEA. An FMEA should be used to define those failures that are critical to system performance and to identify when the effects of a failure can be detected using BIT. Without such information, BIT tests can be developed based only on the test engineer's knowledge of how the system works and not on whether a test needs to be developed for a particular fault. Finally, BIT must be a part of the product design or the risks and consequences shown in Table 7.8 can ensue.

Table 7.8 Risks and Consequences of Not Making BIT as a Part of Product Design

Risks	*Consequences*
BIT is designed independently of the product	BIT fails to support operational and maintenance needs
BIT is designed after the fact	MTBF of the BIT is less than that of the product
Production personnel are not consulted on BIT	BIT is ineffective in the factory

7.6 Interfaces and Connections

A problematic area in the design for sustainability is interfaces and connections (I&Cs). Without I&Cs, it would be impossible to remove or perform maintenance on individual items. But in disconnecting and reconnecting items, failures can be induced by mismating parts, cross-threading connectors, damaging interface devices (IDs), and so on. Disconnecting and reconnecting items also accounts for much of the time needed to remove and replace items. Finally, in the case of high-voltage electrical or high-pressure hydraulic and pneumatic connections, damage to the item or injury to personnel can result if precautions are not taken.

The risk and the time associated with connecting and disconnecting items can be minimized through proper design for sustainability. Volume II of MIL-HDBK-470A (DoD 1997) provides hundreds of maintenance design guidelines, many of which are related to I&Cs. Table 7.9 summarizes some of the relevant I&C guidelines. Section 7.10 provides a more complete list.

BIT false alarms, CNDs, and RTOKs are typical interface problems that plague many complex products. The cause can often be traced back to poor or incorrect connections. Problems with electronic units can often be fixed by reseating connectors. Connectors can vibrate loose, if not secured by a positive locking device, pins can oxidize, and dirt or other foreign matter can interfere with proper operation. So, ensuring that the proper types of connectors are used, ensuring that connectors can be easily accessed, and developing the proper procedures and training are important actions for the sustainability engineer during design.

7.7 Safety and Induced Failures

Maintaining a product can pose safety risks or result in induced failures. An induced failure is one caused by human error or misuse. Unsafe conditions also can result from human error and misuse. Mislabeling or lack of labeling, poorly written instructions, omission of warnings, inappropriate choices of displays and controls, and so on can also lead to damaged or failed equipment and to injury or death of operators or sustainers. Safety is always important in designing a product. The potential for hazardous conditions, of course, depends on the nature of the product and its intended use. Safety requirements come from a variety of sources:

- The customer
- Building codes
- Government agencies
- Industry standards

Table 7.9 Design Guidelines for I&Cs

• Use integral locking mechanisms and visual indications that show that connectors are properly seated and locked
• Use keying or asymmetrically shaped connectors to ensure proper alignment
• Use corrosion-resistant materials for connectors to reduce or eliminate the need for scheduled inspections or corrosion prevention measures
• Locate and position electrical connectors such that all pin identification for either half can be easily seen
• Provide separation between grouped connectors to allow make or break of any connection
• Use quick disconnects to simplify replacement
• Design electrical connectors so that plugs are cold and receptacles are hot
• Use positive locking, quick disconnect connectors to save labor hours, prevent foreign object damage (FOD), and decrease the chance of personal injury
• Use fiber-optic technologies rather than conventional interconnect concepts to reduce the number of interconnects/interfaces, reduce manufacturing and ownership costs, and significantly improve reliability and maintenance
• Standardize connector and wire types to improve testability and logistic support. Keep the number of "different" standard connectors to a minimum. Use the same connector type keyed differently where possible
• Use torque-set or torque-limiting mechanical connections to prevent failures due to over-torque
• Avoid using cotter pins, safety wire, safety clips, and similar devices to prevent maintenance-induced events leading to ground vehicle accidents or loss of air vehicles
• Locate, position, and orient connectors to prevent the need for sequential installation or removal
• In instances where connector interfaces cannot or are not keyed for a specific orientation, all identification, markings, cautions, and directions should be placed 360° around the interface
• Design interface connectors so that a distinct action is required by an individual to make a disconnection
• Design mating items so they cannot be installed improperly or backward

In the United States, an independent regulatory agency, the Consumer Product Safety Commission (CPSC), is charged with protecting consumers from hazardous products. The CPSC imposes federal regulations only when it believes industry's voluntary efforts are insufficient. In addition, a wide variety of consumer products are tested by Underwriters Laboratory (UL), an independent not-for-profit product safety testing and certification organization.

But product designers should do more than simply ensure that an item meets applicable government standards or can earn the UL Mark. UL approval, for example, is not always an indication that a product is safe. First of all, UL does not always consider factors that can affect the long-term integrity of a product and rarely tests products once they leave the factory. Second, in a number of cases, the CPSC has disagreed with UL's test methods and their findings regarding the safety of a product. In addition, regulations, codes, and UL testing cannot address every aspect of every product, especially products incorporating leading edge technology.

For these and other reasons, an overall system safety program is recommended for all but the most innocuous of products. The principal objective of a system safety program is to ensure that safety, consistent with operational and functional requirements, is designed into systems, subsystems, equipment and facilities, and their interfaces. Such a program helps ensure that the designer will thoroughly consider safety in all design trades and design for safe operation, safe maintenance, and some tolerance to human error.

MIL-STD-882C, System Safety Program Requirements (DoD 1993), has guidelines for developing and implementing a system safety program. This program is sufficiently comprehensive to identify the hazards of a system and to impose design requirements and management controls to prevent mishaps by eliminating hazards or reducing the associated risk to a level acceptable to the managing activity. Four different categories of program elements are addressed in MIL-STD-882C, as shown in Table 7.10. The terms and acronyms are unique to MIL-STD-882C and are therefore included in Table 7.11 to aid the reader.

A system safety program needs to be tailored to the product and program requirements. The requirements of MIL-STD-882C can be tailored by selecting only those elements applicable to a given situation. Table 7.12 provides some guidance in selecting safety tasks.

Table 7.10 MIL-STD-882C Safety Program Elements

Category	*Category Description*	*Elements*
Program management and control	Those activities primarily related to management responsibilities dealing with the safety of the program and less to the technical details involved	System safety program A basic system safety program consists of the following safety related elements
		• *System safety program plan*. This plan describes in detail those elements and activities of safety system management and system safety engineering required to identify, evaluate, and eliminate hazards, or reduce the associated risk to a level acceptable to the managing activity throughout the system life cycle. It normally includes a description of the planned methods to be used to implement a system safety program plan, including organizational responsibilities, resources, methods of accomplishment, milestones, depth of effort, and integration with other program engineering and management activities and related systems.

Table 7.10 MIL-STD-882C Safety Program Elements (*Continued*)

Category	*Category Description*	*Elements*
		• *Integration/management of associate contractors, subcontractors, and architect and engineering firms*. This element consists of appropriate management surveillance procedures to ensure uniform system safety requirements are developed.
		• *System safety program reviews/audits*. This element is a forum for reviewing the system safety program, to periodically report the status of the system safety program, and, when needed, to support special requirements, such as certifications and first-flight readiness reviews.
		• *System safety group (SSG)/system safety working group (SSWG) support*. This element is a forum for suppliers and vendors to support SSGs and SSWGs established in accordance with government regulations or as otherwise defined by the integrating supplier.
		• *Hazard tracking and risk resolution*. This element is a single closed-loop hazard tracking system to document and track hazards from identification until the hazard is eliminated or the associated risk is reduced to an acceptable level.
		• *System safety progress summary*. This element consists of periodic progress reports summarizing the pertinent system safety management and engineering activity that occurred during the reporting period.
Design and integration	Activities that focus on the identification, evaluation, prevention, detection, and correction or reduction of the associated risk of safety hazards by the use of specific technical procedures	• *Preliminary hazard list (PHL)*. Identifies any especially hazardous areas for added management emphasis. The PHL should be developed very early in the development phase of an item.

(*Continued*)

Table 7.10 MIL-STD-882C Safety Program Elements (*Continued*)

Category	*Category Description*	*Elements*
		• *Preliminary hazard analysis (PHA)*. Identifies safety-critical areas, evaluate hazards, and identifies the safety design criteria to be used.
		• *Safety requirements/criteria analysis (SRCA)*. Relates the hazards identified to the system design and identifies or develops design requirements to eliminate or reduce the risk of the hazards to an acceptable level. The SRCA is based on the PHL or PHA, if available. The SRCA is also used to incorporate design requirements that are safety related but not tied to a specific hazard.
		• *Subsystem hazard analysis (SSHA)*. Identifies hazards associated with design of subsystems including component failure modes, critical human error inputs, and hazards resulting from functional relationships between components and equipments comprising each subsystem.
		• *System hazard analysis (SHA)*. Documents the primary safety problem areas of the total system design including potential safety critical human errors.
		• *Operating and support hazard analysis (O&SHA)*. Identifies associated hazards and recommends alternatives that may be used during all phases of intended system use.
		• *Occupational health hazard assessment (OHHA)*. Identifies human health hazards and proposes protective measures to reduce the associated risks to levels acceptable to the managing activity.
Design evaluation	Activities that focus on risk assessment and the safety aspects of tests and evaluations of the system and the possible introduction of new safety hazards resulting from changes	• *Safety assessment*. A comprehensive evaluation of the mishap risk that is being assumed prior to the test or operation of a system or at the contract completion.

Table 7.10 MIL-STD-882C Safety Program Elements (*Continued*)

Category	*Category Description*	*Elements*
		• *Test and evaluation safety*. Ensures that safety is considered (and safety responsibility assigned) in test and evaluation to provide existing analysis reports and other safety data and to respond to all safety requirements necessary for testing in-house, at other supplier facilities, and at government ranges, centers, or laboratories.
		• *Safety review of engineering change proposals (ECPs) and requests for deviation/waiver*. Performing and documenting the analyses of ECPs and requests for deviation/waiver to determine the safety impact, if any, upon the system.
Compliance and verification	Activities directly related to the actual verification or demonstration that all legal and contractual safety requirements have been compiled with	• *Safety verification*. Verification is conducted to verify compliance with safety requirements by defining and performing tests and demonstrations or other verification methods on safety-critical hardware, software, and procedures.
		• *Safety compliance assessment*. Performing and documenting a safety compliance assessment to verify compliance with all military, federal, national, and industry codes imposed contractually or by law. This element is intended to ensure the safe design of a system and to comprehensively evaluate the safety risk that is being assumed prior to any test or operation of a system or at the completion of the contract.
		• *Explosive hazard classification (EHC) and characteristics data*. Ensures the availability of tests and procedures needed to assign an EHC to new or modified ammunition, explosives (including solid propellants), and devices containing explosives and to develop hazard characteristics data for these items.
		• *Explosive ordnance disposal source data*. Ensures that the following resources are available as needed: source data, explosive ordnance disposal procedures, recommended "render safe" procedures, and test items for new or modified weapons systems, explosive ordnance items, and aircraft systems.

Table 7.11 Definition of Safety Terms and Acronyms

Term	*Definition*
Fail safe	A design feature that either ensures that the system remains safe or in the event of a failure, forces the system to revert to a state which will not cause a mishap.
Hazard	A condition that is prerequisite to a mishap.
Hazard probability	The aggregate probability of occurrence of the individual events that create a specific hazard.
Hazardous material	Anything that due to its chemical, physical, or biological nature causes safety, public health, or environmental concerns that result in an elevated level of effort to manage.
Mishap	An unplanned event or series of events that result in death, injury, occupational illness, or damage to or loss of equipment or property or damage to the environment. An accident.
Risk	An expression of the possibility of a mishap in terms of hazard severity and hazard probability.
Risk assessment	A comprehensive evaluation of the risk and its associated impact.
Safety	Freedom from those conditions that can cause death, injury, occupational illness, or damage to or loss of equipment or property or damage to the environment.
Safety-critical	A term applied to a condition, event, operation, process, or item of whose proper recognition, control, performance, or tolerance is essential to safe operation or use; e.g., safety-critical function, safety-critical path, or safety-critical component.
Safety-critical computer software components	Those computer software components and units whose errors can result in a potential hazard, or loss of predictability or control of a system.
System safety	The application of engineering and management principles, criteria, and techniques to optimize safety within the constraints of operational effectiveness, time, and cost throughout all phases of the system life cycle.

Table 7.12 Guide to Selecting Safety Tasks

Task	*Type of Task*	*Program Phase*
System safety program plan	Management	Generally applicable in all phases of a product's life.
Integration/management of associate contractors, subcontractors, and architect and engineering firms	Management	Most applicable during design and production. May be applicable during operation if other firms involved in engineering changes, maintenance, and so on.
System safety program reviews/audits	Management	Most applicable during design and production. Periodic reviews during operational life may be appropriate.
SSG/SSWG support	Management	Most applicable during design and production. May be applicable during operational use, depending on the nature of the product.
Hazard tracking and risk resolution	Management	Most applicable during design and production. May be applicable during operational use, depending on the nature of the product.
PHL	Engineering	Most applicable during design.
PHA	Engineering	Most applicable during design.
SRCA	Engineering	Most applicable during design (develop prior to start of design).
SSHA	Engineering	Most applicable during design.
SHA	Engineering	Most applicable during design. May be applicable during operational use, depending on the nature of the product.
O&SHA	Engineering	Most applicable during design. May be applicable during operational use, depending on the nature of the product.
OHHA	Engineering	Generally applicable in all phases of a product's life.

(*Continued*)

Table 7.12 Guide to Selecting Safety Tasks (*Continued*)

Task	*Type of Task*	*Program Phase*
Safety assessment	Engineering	May be applicable in all phases of a product's life.
Test and evaluation safety	Management	Most applicable during design and production.
Safety review of ECPs and requests for deviation/waiver	Management	Most applicable during design and production.
Safety verification	Engineering	Most applicable during design. May be applicable during production.
Safety compliance assessment	Management	May be applicable in all phases of a product's life.

7.8 Standardization and Interchangeability

Standardization and interchangeability are important, interrelated, sustainability design factors. Interchangeability is one of the principal means by which standardization is achieved. Good examples of the close relationship between standardization and interchangeability are the standard size base for incandescent lamps and the standard size male plug for electrical appliances. Standardization is a design feature for restricting the feasible variety of items that will meet the hardware requirements. Standardization includes not only parts but also engineering terms, principles, practices, materials, processes, and software. Standardization encourages the use of common items. It is important that sustainability engineers strive for the design of assemblies and components that are physically and functionally interchangeable with other similar assemblies and components of the system. Standardization design will reduce the need for expensive support facilities at all levels of maintenance. Standardization, a major objective of sustainability, helps achieve the following goals:

- Minimizing both the acquisition and support costs of a system
- Increasing the availability of mission-essential items
- Reducing training requirements both in number of personnel and the level of skill required
- Reducing inventories of repair parts and their associated documentation

Despite the advantages offered by standardization, a system should not necessarily be built around a standard item—particularly if the standard item does not meet the required performance and has a record of poor reliability or costly maintenance—or the standard item may satisfy a safety requirement in most environments but not in the unusual environment for which it is being considered. Technological advances may also dictate the development of new material or provide a superior product to replace an existing one.

Interchangeability is the ability to exchange parts or assemblies between similar equipment, without having to alter or physically change the item. This is an extremely important life cycle cost design requirement. Total interchangeability exists when two or more items are physically and functionally interchangeable in all possible applications; that is, when the items are capable of full, mutual substitution in all directions. *Functional* interchangeability is attained when an item, regardless of its physical specifications, can perform the specific functions of another item. *Physical* interchangeability exists when two or more parts or units made to the same specification can be mounted, connected, and used effectively in the same position in an assembly or system. The two broad classes of interchangeability are

- *Universal interchangeable*—Items that are required to be interchangeable in the field even though manufactured by different facilities.
- *Local interchangeable*—Items that are interchangeable with other components made by the same facility but not necessarily interchangeable with those made by other facilities. This may result from different sets of measurement units employed in their design and manufacture.

7.9 Design Tools

To assist in the design of sustainable products, various types of design tools have been developed. These tools can be categorized as analytical, mock-ups, simulation and VR, handbooks and other reference documents, expert systems, and neural networks. These categories are discussed in the following subsections.

7.9.1 Analytical Tools

Most analytical tools available today to assist the designer in designing a sustainable product are related to modeling the human being. Since the late 1970s, more than 50 different human models have been developed. Electronic representations of human forms are used to simulate equipment assembly, operation, and maintenance during the design process. They allow engineers to identify and resolve human interface problems before hardware is built. Early human models used only hands or arms to check clearances for tool manipulation. Today's models create whole-body representations using a basic "link" system resembling a human skeleton to enable posturing of the model within the work environment.

Although a large variety of human models have emerged to support the design effort, few experts agree on how the human form should be configured, what constitutes valid data, what are acceptable levels of accuracy, and what software and communications standards should be adopted. Earlier human models focused on the physical or ergonomic aspects of human/machine interaction. The focus today is on integrating this information with visual and cognitive information processing requirements and with human modeling simulation to create an integrated modeling technology. This provides additional realism not only through accurate replication of human anthropometry, biomechanics and movement but also in simulating purposeful and logical behaviors in response to external stimuli and workload. The purpose of all these models is to integrate human performance analysis with computer-aided design to provide the design team with a high degree of visualization of human performance capabilities and limitations with respect to the product design. Through integration of graphic human models with computer-aided design product models, "rapid prototyping" of human/product simulations or their results can be passed back to equipment designers for resolution of identified problems.

Designing equipment that is easy to operate, assemble, and sustain is often hindered by poor communications between the design team and personnel familiar with the operation, assembly, or maintenance of similar or existing equipment. Improved communication among integrated product development (IPD) team members can be accomplished by simulating equipment operation, assembly, and maintenance using human modeling technology. Human models combine animated 3D human mannequin geometry with equipment geometry to "walk through" designs so that problems can be solved early in the design process. They help to ensure that human-centered design information is readily and accurately documented and preserved to aid in human resources and related logistics planning requirements for system support. The models are used first to influence a product's design for supportability, and then to document the product requirements for human and logistics resources. Another major objective is the development and implementation of design evaluation technology for performance of "design checking" and prescriptive human performance information for recommending corrective action to equipment designers to conform to human performance requirements. The term "human model" in this context refers to the 3D, computer graphic representation of a human form for analysis purposes. It does not address human performance models that are independent of the geometric aspects of the human body (e.g., human error models).

Human modeling systems can support both the design requirements definition and design evaluation when concepts are only represented in 3D computerized form. The human design requirement definition can be accomplished using reach or vision envelopes that describe the minimum conditions a designer must satisfy for physical or visual access. Design evaluations, on the other hand, usually focus on critical task segments in which the human/equipment interface is tested for compliance with stated design requirements and freedom from "won't-fit" or "won't-work" conditions.

Using human modeling in computer-aided design provides important benefits including:

- Eliminating most physical development fixtures by performing evaluations electronically
- Reducing design costs by enabling the IPD team to prototype more rapidly and test a design among themselves
- Avoiding costly design fixes later in the program by considering human factors requirements early in the design effort
- Improving customer communications during product development by using compelling animated graphics to review and confirm equipment function

Application of human modeling technology is likely to impact how engineers design, build, and test products in the future. Those who are responsible for manufacturing planning, tool design, or sustainability engineering will be able to communicate with structural and systems engineering effectively to illustrate assembly or maintenance problems associated with new designs. It is expected that human model applications will spread beyond what is traditionally called engineering and be used by various IPD team members from factory-built units to product support groups.

A variety of suppliers have human modeling software programs. Unfortunately, they have created models that are very different in functionality and in user interface, and in the underlying data driving the mannequins. This diversity has created not only models that look and behave differently but also models that produce distressingly different results when performing the same engineering analysis. For these reasons, the Society of Automotive Engineers (SAE) has formed an ad hoc committee to formulate standards to promote the orderly growth of this technology. The SAE Human Modeling Technology committee has established three major subcommittee activities: user requirements, human model definition, and software standards. A fourth subcommittee activity is being considered on the topic of human performance models that would address human error prediction, human workload, and task time estimation.

7.9.2 Mock-ups

As products became more complex, conceptualizing shape and fit from a 2D drawing became increasingly difficult. As a preproduction version or prototype of the product was constructed, the consequences of inaccurate conceptualization evidenced itself in structural components that would not properly mate, hydraulic lines that did not connect as planned, and so on.

To solve this problem, engineers began using mock-ups of critical sections of the product, often the entire product. Constructed of inexpensive materials, mock-ups are non-functioning, dimensionally accurate, and often full-scale models of the product. Mock-ups allow the fit and mating of components to be checked before constructing any functional hardware. Although being supplanted by computer-aided design and VR, mock-ups are still useful due to their simplicity and relatively low cost.*

7.9.3 Simulation and VR

Simulation, as used here, is a method for representing or approximating an object, event, or environment. VR is a new technology that has been defined as the total or near-total immersion of an observer in a 3D, synthetic environment in which the observer interacts with the environment. Simulation is frequently used to evaluate the maintenance characteristics of a design. Simulation can include physical mock-ups, computer models, or mathematical models. VR is the newest and most technologically advanced form of simulation. Jaron Lanier, founder of VPL Research, initially coined the term “virtual reality” in 1989 (Lanier 1992a and Lanier 1992b). Other related terms include “artificial reality” (Krueger 1991) and “cyberspace.” William Gibson coined the term “cyberspace” in his short story Burning Chrome (Gibson 2003). More recent related terms are “virtual worlds” and “virtual environments.”

Today, the term “virtual reality” is used in a variety of ways and often in a confusing and misleading manner. Originally, the term referred to “immersive virtual reality.” In immersive VR, the user becomes fully immersed in an artificial, 3D world completely generated by a computer. The unique characteristics of immersive VR can be summarized as follows:

- Head-referenced viewing provides a natural interface for the navigation in 3D space and allows for look-around, walk-around, and flythrough capabilities in virtual environments (VEs).
- Stereoscopic viewing enhances the perception of depth and the sense of space.
- The virtual world is presented in full scale and relates properly to the human size.
- Realistic interactions with virtual objects via data glove and similar devices allow for manipulation, operation, and control of virtual worlds.
- The convincing illusion of being fully immersed in an artificial world can be enhanced by auditory, haptic (manipulators used to provide force or tactile feedback to humans interacting with virtual or remote environments), and other nonvisual technologies.
- Networked applications allow for shared VEs.

Currently, the term “virtual reality” is also used for applications that are not fully immersive. The boundaries are becoming blurred, but all variations of VR will be important in the future.

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* Very sophisticated mock-ups have been constructed. For example, an expensive, full-scale, left half (bisected down the longitudinal axis) of the B-1A bomber was built by Rockwell. The wing was a swept wing. Normally, mock-ups are relatively simple and inexpensive.

These include mouse-controlled navigation through a 3D environment on a graphics monitor, stereo viewing from the monitor via stereo glasses, stereo projection systems, and others. Internet "surfers" are familiar with Apple's QuickTime VR, in which photographs are used to model 3D worlds and provide pseudo look-arounds and walk-throughs of a landscape or object. In general, VR is a method of simulating an environment that

- Is too dangerous for an observer
- Lacks elements, such as an aircraft or other item of study
- Does not exist
- Is not accessible

Three different types of VR have been developed. Although not all these types exactly fit the definition of VR, they do represent variations of the same basic technology. The three types of VR are

- Telepresence, in which observers perceive and interact with a distant environment
- Augmented reality, a combination of a real and synthetic environments, in which a real environment is annotated or augmented with additional details or elements
- VR, in which a synthetic environment is created for the observer (immersive)

Telepresence is used when the environment is dangerous or inaccessible. An example of the former case is disarming a bomb, a hazardous task for a person, even if wearing a helmet, body armor, and other safety devices. A robot equipped with telepresence can be operated by an operator located at a safe distance from the bomb with almost the same feeling of "being there" as if he or she were actually at the site of the bomb. An example of the latter case is controlling robots in earth orbit from a ground station on earth.

In augmented reality, information and details are "added" to the real world, providing guidance, instructions, and so on, to help an observer's understanding or performance. Three examples follow. First, in an augmented reality approach to video-conferencing, a 3D image of a new product still in design could be generated from computer-aided design files and "placed" on the desk or table in front of each conferee. The nomenclature of parts could be "superimposed" on them and would "follow" them no matter how they were moved within the range of the video camera. Another example of the use of augmented reality is the superimposing of the proper locations for drilling holes in an aircraft skin with other information, such as proper hole size. Finally, surfaces or features of an item that are physically occluded can be displayed as an overlay so that an observer can "see" them without disassembling the item.

In a total VR environment, nothing (or very little) but the user is "real." Objects and their physical characteristics, the physical environment, the time of day, and so on, are all generated by a computer and displayed to the user, usually through goggles or a head-mounted display (HMD). The user "sees" and can interact with objects in the environment. Input devices are needed to allow the user to navigate through and interact with the VE. Such devices include data gloves, joysticks, and hand-held wands. In addition, directional sound, tactile and force feedback devices, voice recognition, and other technologies are now used to enrich the immersive experience and to create more "sensualized" interfaces. The HMD was the first device that provided an immersive VR experience. Evans and Sutherland demonstrated a head-mounted stereo display in 1965. Twenty four years later, the first commercially available HMD, the EyePhone, came from VPL Research. A typical HMD houses two miniature display screens and an optical system. The optical system channels the images from the screens to the eyes, thereby presenting a stereo view of a virtual world. A motion tracker continuously measures the position and orientation of the user's head and allows the image-generating computer to adjust the scene representation to the current view. Consequently, the viewer can walk through and observe the surrounding VE. HMDs are often uncomfortable, intrude on the VR experience, and cannot be worn for extended periods of time. To overcome these problems, alternative concepts for immersive viewing of VEs were developed. Two of these alternatives are BOOM (Binocular Omni-Orientation Monitor) and CAVE (Cave Automatic Virtual Environment).

The BOOM from Fakespace is a head-coupled stereoscopic display device. A box houses screens and optical system and is attached to a multilink arm. By looking into the box through two holes, the observer sees the virtual world, and can guide the box to any position within the operational volume of the device. Sensors in the links of the arm that holds the box track the observer's head.

Researchers at the University of Illinois at Chicago developed the CAVE. CAVE immerses observers in an environment created by projecting stereo images on the walls and floor of a room-sized cube. The cube can accommodate several persons who can walk freely inside the CAVE. Observers wear lightweight stereo glasses. A system that tracks the heads of the observers continuously adjusts the stereo projection to the current position of the leading viewer.

VR has definite applications for designing sustainable equipment. For example, based on computer-aided design data files, a virtual copy of the product can be "produced." The maintenance engineer can then enter a VE in which maintenance can be "performed" on the product. The accessibility of components, whether an item fits in an allocated space, and the approximate time required to perform specific maintenance actions all can be evaluated using VR. Virtual copies of support equipment, such as dollies and lifting devices, can be evaluated by "performing" maintenance activities with them. VR maintenance aids could allow technicians to view virtual information panels "superimposed" (using augmented reality techniques) on the actual equipment. In general, the maintenance engineer can use VR to analyze:

- Reachability and access
- Field of view
- Integrated displays
- Attention skills
- Powered hand tools evaluation
- Posture
- Energy expenditure
- Human–machine interface
- Stressor effects on human performance
- Lifting guidelines
- Activity timing
- Cognitive skills, decision making
- Ergonomic analysis of maintenance workstations

In addition to designing for sustainability, VR has many potential training applications. Maintenance and manufacturing procedures, especially procedures that are seldom performed or are difficult to teach using conventional approaches, can be taught using VR. VR could also be used to train individuals in performing hazardous procedures, disposing hazardous materials, or performing life-threatening procedures. For example, surgeons can now "perform" operations without actually using any physical tools or a live patient. As has been the case with previous new technologies, the possible uses of VR cannot be fully appreciated or anticipated. As VR matures, the applications related to design for maintenance will certainly increase in number and in fidelity.

7.9.4 Handbooks and Other Reference Documents

Hard copy handbooks and similar reference documents are considered by some to be passé in today's world of computer-based design and VR. Nonetheless, much of the knowledge gained over the years as well as new information are documented in handbooks, manuals, data books, and so on. Guidance, rules-of-thumb, lessons learned, and similar information, together with explanations, make handbooks and other reference documents important resources for the engineer. Some older documents are being "digitized" for entry into computer databases making it easier to search and update the information. Nearly all new documents are created in digitized form.

7.9.5 Artificial Intelligence

Various forms of artificial intelligence (AI) are beginning to be used in the field of sustainability, particularly in the design of diagnostic tools. Individual AI techniques include expert systems, fuzzy logic, and neural networks. The structural basis and respective advantages and disadvantages for each of these techniques are summarized in Table 7.13.

7.9.5.1 Expert Systems

Expert systems are becoming an important sustainability tool, especially as industry downsizes with a concomitant loss of individual company "maintenance experts." Expert systems are used to "capture" and codify the knowledge of one or more experts in a given field or area of study and to make this knowledge available to nonexperts.

For sustainability, a major use of expert systems is in diagnostic tools. The diagnostic capability of expert systems has been successfully demonstrated in both the medical and maintenance fields. Whether the problem is to identify a specific illness afflicting a patient or to identify the cause of an observed system or equipment failure, expert systems have proved to be efficient and effective.

Another potential use of expert systems comes as a result of "downsizing" and the use of integrated product design teams (IPDTs). As companies have downsized, the number of individuals employed as maintenance engineers has decreased. Many years of corporate experience are being lost and the few remaining maintenance engineers are spread thin. Where IPDTs are used, an engineer who may know very little about sustainability may very well be given the responsibility for that aspect of design. Expert systems can help "replace" the maintenance engineer and assist those given the responsibility for maintenance design. As part of a computer-aided design system, an expert system could guide the designer in equipment placement, selection of fasteners, design of access panels and hatches, and so on.

Two distinct types of expert systems are used: rule based and model based.

7.9.5.1.1 Rule-Based Expert Systems

Rule-based expert systems operate through a set of "IF…THEN" rules processed by an underlying "inference engine." A typical rule-based expert system is composed of four major elements: the inference engine, a knowledge base, a user interface, and an explanation facility. The *inference engine* is that part of the expert system that performs the reasoning. It is analogous to the raw intelligence of a human expert. Many different forms of inference engines exist, but all are designed to perform the same task; that is, to examine the current facts and use available rules to generate new facts. The *knowledge base* is where the information resides within the expert system. It consists of two distinct parts: the rule base "IF <condition> THEN" and the fact base containing simple

Table 7.13 Comparison of AI Techniques

Technique	*Basis*	*Advantages*	*Disadvantages*	*Application to Maintenance*
Rule-based expert system	"IF…THEN" logic	Audit trail possible.	Difficult to capture "intuitional" rules.	Expert systems for design and for fault diagnosis. Based on knowledge of human "experts."
Model-based expert system	Functional system model	Specific models are available.	Requires the development of a unique model for each problem.	Expert systems for design and for fault diagnosis. Adds model of problem to expert knowledge.
Fuzzy logic	Converts discrete logic into continuous values	Eliminates stepwise approximations. Easy to "Fine Tune."	Each individual output must be "defuzzified."	Expert systems for design and for fault diagnosis. Allows for nondiscrete I/O.
Neural network	Numerous interconnected simple processing modes	Trained by example. Insensitive to "Noise." Able to capture "intuitional" rules.	No theoretical understanding. No practical guidelines. No audit trail possible.	Expert systems for design and for fault diagnosis. Can be "trained" by nonexperts. Can capture intuitional and procedural rules.

statements about the condition of the world as it is applicable to the problem under study. The *user interface* enables the expert system and the user to communicate. The exact form of this interface depends on the intended audience for the expert system. The *explanation facility* presents the user with the expert system's justification for its conclusions (i.e., an audit trail) as necessary.

A typical expert system initially partitions the problem by applying a broad set of inference rules to an initial set of data describing the problem or the symptoms. Each of these inference rules will take the inference engine to a further data acquisition stage (typically another, more directed, questionnaire) or the establishment of a new fact. This process of a directed search with additional data gathering continues until the expert system has reached a leaf node in the resulting decision tree. Some inference engines may resolve an ambiguity, when several inference rules evaluate as

TRUE to a given data set, by selecting the one with the highest associated weighting or confidence factor; others may use a different approach (e.g., fuzzy logic). The rules in the knowledge base, that portion which drives any expert system, are painstakingly constructed by an expert systems specialist interrogating the knowledge expert and subsequently codifying the often imprecise descriptions of their thinking processes into inference rules, possibly with numerical limits. For example, a rule for a medical diagnostic expert system may be stated as follows:

> IF heart rate > 100 beats per minute AND body temperature >101°F THEN recommend that patient be placed in an ice bath.

The fact portion of the knowledge base would simply record the patient's heart rate and temperature. A general approach for the physical development of a maintenance expert system may be

1. Design expert system structure including user interface
2. Knowledge acquisition
3. Rules codification
4. System validation
5. Growth or system enhancement

It may be difficult to capture all of an expert's knowledge in an expert system knowledge base because the expertise is encoded as a causal relationship. "Rational" knowledge, where the solution can be described analytically, is comparatively straightforward to codify into inference rules. "Semirational" knowledge, where the expert can specify suitable ranges for conditions, but cannot (easily) defend the choice of these ranges, is more difficult. This process may take some detective work by the expert system specialist. Unfortunately, however, much of what "makes an expert" occurs at an intuitional or visceral level, where even the expert is unaware of the underlying mechanism behind their decisions and may even be unable to quantify appropriate ranges. This area presents the major challenge and limitation in the design of a rule-based expert system. The following three sections will address some alternative solutions to this problem.

7.9.5.1.2 Model-Based Expert Systems

The second type of expert system—the model-based system—uses a specific functional model to diagnose the observed symptoms and devise a solution to the problem. The knowledge base is usually organized around a functional or representative model of the system, but it is sometimes preferable to use an actual physical model. This model now provides the procedure with a focus of attention directed toward expected goals and guides the process in determining the effects of system/equipment failure symptoms. In the area of testability, a number of detailed models have been developed.

7.9.5.1.3 Fuzzy Logic

Fuzzy logic is essentially an expert system structure tailored to deal with continuous-valued inputs and outputs (I/O) instead of discrete lexical elements. Thus, fuzzy logic can potentially reduce the number of rules required in a system. This is achieved through clever preprocessing of the inputs, where each continuous input value is "fuzzy" or converted from a precise numeric value to a degree-of-membership in a "fuzzy set" as shown in Figure 7.4. Fuzzy logic is attractive because it allows for conflicting "expert opinion," thereby allowing the use of information normally excluded

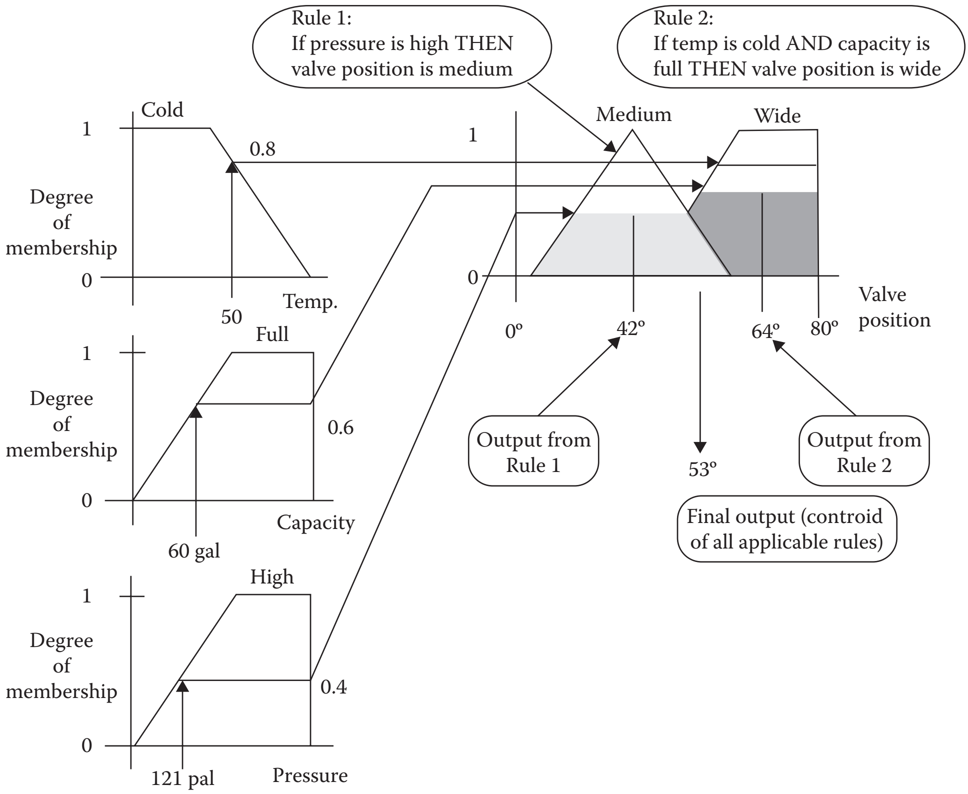

Figure 7.4 Fuzzy logic set membership.

from scientific models. For design, fuzzy logic can be used to define a range of feasible design parameters even when historical data are insufficient to use tractable probability-based approaches.

When an input falls into a region where two or more fuzzy sets overlap, it simply produces a degree-of-membership in each of the overlapping sets. An output term of a fuzzy logic system is itself a fuzzy set, which must converted back to a precise (i.e., "crisp") numeric value. This is done by taking the centroid of the part of the output fuzzy set lying below the degree-of-membership output value. This degree-of-membership can result from a straight mapping of input fuzzy set to output fuzzy set, as shown by Rule 1 in Figure 7.4 or from a logical combination of rules* as used in an expert system (Rule 2 in Figure 7.4). When two or more inference rules trigger on a given output, the "crisp" output is calculated as the centroid of the areas of the contributing rules.

Providing the means for an expert system structure to treat continuous I/O as lexical elements eliminates the stepwise approximation a classical expert system would normally be forced to use in such a situation. This significantly reduces the number of inference rules required and clarifies the program structure. Also, because the mapping between inputs, outputs, and lexical elements is done via simple curve functions, a fuzzy system is easier to "fine tune." Thus, a given fuzzy solution can be taken to other similar domains by rescaling or reshaping the I/O curves while leaving the logical inferences unchanged.

* The AND operator selects the smallest degree-of-membership of its operands, whereas the OR operator selects the largest degree-of-membership.

7.9.5.2 Neural Networks

Artificial neural networks consist of a large number of densely interconnected simple processing nodes, each of which produces a nonlinear result of a weighted sum of its inputs (e.g., the output is a binary "1" if the sum exceeds a set threshold). The input stimuli and/or the outputs of other neurons are typically shown in Figure 7.5. Although there are numerous architectures of neural networks, they all work by partitioning the N-dimensional stimulus space into a series of continuous regions and as such, serve as "feature detectors" where the output (1,0) of an output-stage neuron represents the presence or absence of a desired feature. This behavior is especially useful in pattern recognition.

Neural networks, unlike expert systems or fuzzy logic, do not partition the stimulus space based on explicit rules. Rather, they are "trained" with sets of example stimuli and desired outputs. The training procedure gradually adjusts the weighting coefficients on each neuron's input until the global error is minimized. Successive training sets for other stimulus response sets alter the coefficients, but a "memory" of previous training sets remains. Given a sufficient number of training sets, the neural network gradually converges to a stable set.

Neural nets have four significant advantages over expert systems:

1. Although slow to train, neural nets can be trained by someone who is not an expert in the field (the training data sets, however, must be prepared by such an expert), which can translate into time and cost savings.
2. Because the network is trained by example, it can capture the intuitional expertise as well as the procedural aspects.
3. The neural net partitions the stimulus space into contiguous regions, eliminating the gaps, overlaps, and understatement problems inherent in expert systems.
4. Neural networks have been shown to be robust in the face of the noisy data found in nature. They require little or no sensor calibration or special nonlinear quantization schemes.

Several factors, however, mitigate against the use of neural networks. These include

1. The lack of a sound theoretical understanding of neural networks.
2. The absence of practical guidelines for selecting from the multitude of competing architectures often makes the choice one of personal taste.

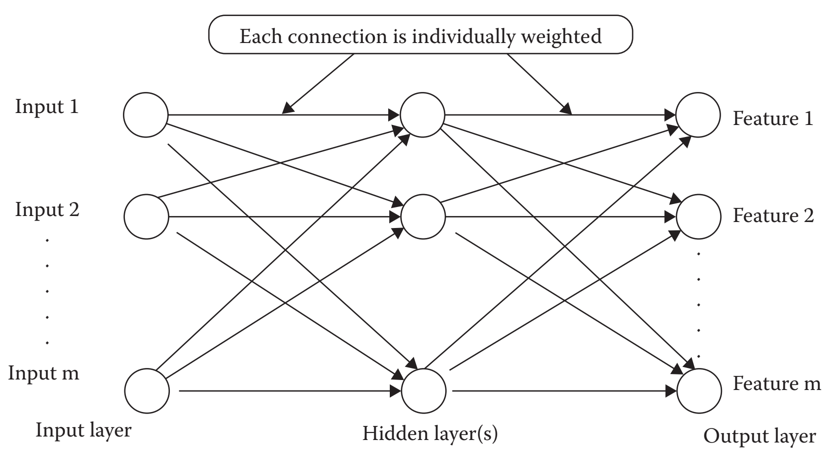

Figure 7.5 Typical neural network configuration.

3. The lack of an established means for determining the correct number of neurons to use in a given architecture for a given problem. Practitioners typically add neurons until they achieve a desired level of network stability.
4. The sensitivity of neural networks to the training data. With too little training, neural nets tend to misidentify stimuli (i.e., mispartition stimuli space). They can also exhibit pattern sensitivity to some data sets. That is to say, the network will not converge to a stable configuration but oscillates between two or more metastable regions.
5. The rapid growth in the number of neurons and divergence that often result from attempts to deal with metastability.
6. The inability of neural networks to provide an audit trail showing how or why a decision was made. This makes them much harder to debug than expert systems and also poses some interesting liability issues.

In summary, neural networks provide several distinct advantages over classical expert systems, most notably, (1) training by example, (2) robust pattern matching in the face of noisy or incomplete data, and (3) the ability to capture an expert's intuitive knowledge. However, they operate "mysteriously," in a field with few landmarks. This makes neural network solutions difficult to develop.

7.10 Design Guidelines

Table 7.14 provides some guidelines for a design for sustainability. These guidelines were developed by Raytheon in 1972 and are listed in Volume II of MIL-HDBK-470A (DoD 1997). Note that even though the Raytheon guidelines were developed years ago, the ones included here are still relevant.

Table 7.14 Design Guidelines

General
• Identify all RUs and assemblies • Incorporate self-test at the lowest practical economical level of assembly • Simplify decision making by specifying go/no-go test techniques • Ensure maintenance procedures call for a logical sequence of tasks
Modularity
• Design modules in uniform sizes and shapes as is practical • Design modules for complete functions to minimize interconnections and problems of signal tracing and to facilitate troubleshooting • Design modules to permit operational testing of the modules when removed from the product • Design low-cost and noncritical modules to be "throw-away" • Design modules so that they cannot be placed inadvertently in the wrong location • Use guide pins to facilitate the installation of modules • Design and locate repairable modules for easy accessibility • Use quick disconnect devices on modules to facilitate quick and easy removal

(*Continued*)

Table 7.14 Design Guidelines (*Continued*)

Adjustments and Alignment
• Design equipment to eliminate the need for alignment and adjustments • Design equipment with self-adjusting devices • Design so that disassembly is not required to facilitate adjustments • Alignment and adjustment devices susceptible to vibration or shock should be designed with a positive locking feature • Design so that adjustments can be made by one person • Avoid adjustments where small movements of the adjusting device result in large changes in the affected parameter • Adjustment devices should not be located close to high voltage or hot sections of the equipment
Accessibility
• Design so items can be connected and reconnected without special tools • Design simple connections with few moving parts • Use quick disconnects (self-sealing) in hydraulic/pneumatic systems • Allow adequate space to make connections and disconnections • Design items with safety interlocks to prevent inadvertent disconnect • Design indicators of servicing status of equipment so they are accessible and readable from the ground level for air vehicles and from the operator's position for ground and water vehicles • Equipment bay and compartment structural flanges and stiffeners should be external to the compartment • Mount line replaceable units (LRUs)/subsystems on drawer slides or extender racks to provide easier accessibility during integration, testing, debug, and repair of UUTs • Use a high gloss white to maximize lighting reflectivity, visibility, and rapid leak detection capability in equipment bay and compartment interiors • Provide good access to corrosion-prone structural areas for inspection and treatment • Use transparent windows, quick-opening covers, or openings without any cover to permit quick visual inspections where needed • Use stiffening beads in lieu of flanges to the maximum extent • Locate nutplates or gang channels in accessible areas that do not require extensive disassembly or equipment removal to gain access • Locate identification and modification plates for all major structural assemblies and subassemblies so as to be fully visible and legible when viewed through normal access provisions. Avoid the need to remove equipment or components to view the plates • Provide access to all engine mounts for ground vehicles so that hoisting or crawling under the vehicle is not required • Modularize structural instrument panels, dashboards, and control panels for easy and adequate access to all interfaces, to simplify manufacturing, and to reduce maintenance-induced problems • Provide a sufficient number of compartment fluid drains to ensure fluid drainage

Table 7.14 Design Guidelines (*Continued*)

Human factors (including anthropometric considerations)
• Size structural openings into man-rated fuel cells to enable entry by a 75th percentile male • In designing the vehicle, system, subsystem, and equipment, attempt to satisfy the personnel spectrum from the 5th percentile female to the 95th percentile male • Design hinged access doors and panels that can be placed in an opened position so they do not have sharp edges or corners • Develop decals, placards, and instruction media around an 8th grade reading level and a 10th grade level of comprehension • Group man–machine interfaces manifold style to enable connect/disconnect in a single action • Include an integral, highly visible indicator in a man–machine interface connector to denote connector is seated and locked • Clearly mark all subsystems/LRUs to ease system integration, test, debug, and repair • Use the English language to report failures rather than alphanumeric codes, lights, indicators, and so on.
Mating, interfaces, and connections
• Use integral locking mechanisms and visual indications that show that connectors are properly seated and locked • Use keying or asymmetrically shaped connectors to ensure proper alignment • Use corrosion-resistant materials for connectors to reduce or eliminate the need for scheduled inspections or corrosion prevention measures • Use positive locking, quick disconnect connectors to save labor hours, prevent FOD, and decrease the chance of personal injury • Use fiber-optic technologies rather than conventional interconnect concepts to reduce the number of interconnects/interfaces, reduce manufacturing and ownership costs, and significantly improve reliability and maintainability • Use clamps with torque-set or torque-limiting connections • Use quick disconnects to simplify replacement • Use quick-release cables and locate cables to make removal and replacement easy and to avoid having to remove one cable to gain access to another. Provide adequate space for cables, including sleeving and tie-downs, and adequate service loops for ease of assembly/disassembly • Use torque-set or torque-limiting mechanical connections to prevent failures due to over-torque • Design mating items so they cannot be installed improperly or backward • Design interface connectors so that a distinct action is required by an individual to make a disconnection • Design electrical connectors so that plugs are cold and receptacles are hot. • Design in-line plumbing connections within a fuel tank or cell so that making/breaking the interface can be done by hand, require no torque, contain integral safety locking mechanisms, and do not require safety wire

(*Continued*)

Table 7.14 Design Guidelines (*Continued*)

Mating, interfaces, and connections
• Design carry-through bulkheads, major frames, structural ribs, spars, webs, keels, and manufacturing close-outs with constant web thickness to provide flexibility in locating penetration fittings and simplify structural repair. Avoid stepped chemical milling, stepped machining, stepped composite lay-up, and similar manufacturing techniques • In instances where connector interfaces cannot or are not keyed for a specific orientation, all identification, markings, cautions, and directions should be placed 360° around the interface • Locate, position, and orient connectors to prevent the need for sequential installation or removal • Locate and position electrical connectors such that all pin identification for either half can be easily seen • Locate LRU/subsystem critical nodes (and/or test points) so they are accessible from a connector to prevent the need for internal LRU probing or access • Avoid using cotter pins, safety wire, safety clips, and similar devices to prevent maintenance-induced events leading to ground vehicle accidents or loss of air vehicles
Standardization and interchangeability
• Hangeability exists—to avoid any potentially dangerous situation • Ensure items are not physical interchangeability if functional interchangeability is not intended • Whenever total—functional and physical—interchangeability is impractical, design the items for functional interchangeability, and adapters should be provided to make physical interchangeability possible • Use identical components, such as pumps, reservoirs, and accumulators, in each individual power subsystem • Differences should be avoided, where possible, in the shape, size, mounting, and other physical characteristics of functionally interchangeable items • Modification of parts and units should not change their manner of mounting, connecting, or otherwise alter how they are incorporated in an assembly or system • To remove latent doubt, provide sufficient information in documented instructions and identification plates to enable the technician to decide positively whether or not two similar items are actually interchangeable • Design mounting holes and brackets to accommodate parts and units made by different facilities, that is, make them universally interchangeable • Design exterior structure containing complex integrated antennas or sensors to be interchangeable to enhance repair of battle damage and induced damage • Design parts and assemblies of a given model product or of models of a product in the same series to be interchangeable or replaceable • Standardize parts, fasteners and connectors, lines and cables

Table 7.14 Design Guidelines (*Continued*)

Standardization and interchangeability
• Design parts and assemblies of a given model product or of models of a product in the same series to be interchangeable or replaceable • Standardize parts, fasteners and connectors, lines and cables, and so on throughout a system, particularly from unit to unit within a given system • Design mounting holes and brackets to accommodate parts and units made by different facilities, that is, make them universally interchangeable • Provide total interchangeability for all parts and units that – are intended to be identical – are identified as being identical – have the same manufacturer's part number or other identification – have the same function in different applications (especially important for parts and units that have a high FR), and so on throughout a system, particularly from unit to unit within a given system • Do not develop or identify special tools solely to simplify basic design or development of vehicles, systems, subsystems, or equipment • Fully support the development of, or recommendations for, special tools with appropriate analyses, including life cycle costing, to justify the need • Ensure that BIT system thresholds are consistent with those across all levels of indenture to prevent excessive numbers of CND and RTOK events from occurring
System/subsystem BIT/built-in test equipment (BITE)
• During design of the BIT, use worst-case stress analysis to ensure that any circuit failures induced by temperature extremes, tolerance build-up, power supply variations, and combinations thereof are identified • Limit the amount of data that is recorded to a manageable size by – Limiting the number of signals that are monitored – Limiting the maximum sampling rate – Reducing the time span over which data are accumulated – Restricting the type of data accumulated • Base the degree of BIT required or proposed on the respective FRs and the appropriate FMECA at all equipment indenture levels • Incorporate testability design features as an integral part of equipment preliminary design process • Monitor mission-critical functions with BIT • Design BIT so it is initiated automatically upon equipment power-up • Set BIT tolerances to maximize FD and minimize FAR in the expected operating environment • Use concurrent BIT to monitor system-critical functions • Design the BIT and BITE so that no fault or failure within the BIT or BITE will degrade, disrupt, or fail the system being monitored

(*Continued*)

Table 7.14 Design Guidelines (*Continued*)

System/subsystem BIT/built-in test equipment (BITE)
• Design BIT to have a very low FAR (goal of 1% or less) • Provide for manual control of test sequences so that the test can be selected individually, and appropriate test combinations can be executed at the operator's discretion • Design the failure detection function to provide the equipment operator with a go/no-go indication of equipment readiness • Design BIT to have the same level of electromagnetic interference protection as the item being monitored
FI
• Design each FI test to be independent of all other tests • Design each test so it can be terminated prior to completion and reinitiated at its start point • Ensure that system user manuals include instructions for faults not covered by BIT such as, system will not power-up or system is being used in an incorrect environment such as, at the wrong altitude, and so on. • Clearly mark test points and make them easy to access • Interlock the high power sections of systems and subsystems with visual/audible BIT to ensure safe system activation • Design feedback loops so that the loop can be broken during test to ensure that faults do not propagate to the point where they cannot be isolated
Safety
• Do not locate equipment servicing points in crew, passenger, or operator areas • Do not locate heat exchangers using hot liquids as the heat source, inside the compartments used for operator, crew, or passengers • Route plumbing, lines, or hoses containing hot liquids, toxic gases, or liquids external to operator, crew, or passenger stations • Use identical types of fluid in all hydraulic subsystems. Brakes may be the exception only if the system is totally separated from and independent of other hydraulic systems • For vehicles containing two or more systems with different fluids, use different service fittings and different ground power interfaces for each fluid type • Use cosmetic touch-up and repair materials that are environmentally safe • Design tires with a color band to provide easy visual indication that maximum wear has been achieved • Design stored energy devices (e.g., accumulators, nitrogen bottles, gas generators, etc.) that could cause injury, harm, or damage if inadvertently actuated, with integral safing provisions • Write clear operating or maintenance instructions or procedures that are not easily misinterpreted • Design items that are not functionally interchangeable so they are not physically interchangeable

Table 7.14 Design Guidelines (*Continued*)

Safety
• Properly locate warning labels and place warnings in procedures in the correct sequence • Design blind matings with self-guiding features • Locate high-failure items such that low-failure items do not have to be removed to facilitate maintenance (unnecessarily increasing the removal rate for the latter) • Design the operation of controls to be consistent with intuition and common practice (i.e., a knob is turned clockwise to increase power) • Design informational displays to be easy to read and interpret • Design tasks so they are not physically awkward to perform • Provide electrical grounds for external metal parts, antenna, and transmission line terminals and control shaft bearings • Provide safety covers, warning labels, and interlocks for equipment using voltages greater than 70 V • Use circuit breakers rather than fuses • Provide guards for high-temperature parts • Provide protection from moving parts for maintenance personnel • Round edges and corners and avoid sharp projections, thin edges, and burrs to avoid injuries from cuts or abrasion • Provide guards around lubrication points that are serviced while the equipment is operating
Nondestructive inspection and nondestructive test
• Avoid reliance on extensive interpretation by nondestructive inspection equipment operators to detect structural flaws • Do not use nondestructive inspection technologies to maintain or protect the reliability of an item • Derive nondestructive inspection and nondestructive test requirements from the FMECA and the associated RCM analysis and documentation
Handling
• Provide handles on items that – Are difficult to grasp, carry, or remove – Are frequently carried or handled – Weigh more than 10 pounds – Have fragile components that might be used as handles • Locate single handles over the center of gravity of the item • Place handles so they do not interfere with operation or maintenance of the item • Provide provisions for mechanical handling of items weighing more than 90 pounds

(*Continued*)

Table 7.14 Design Guidelines (*Continued*)

Handling
• Provide hoist lugs with "LIFT HERE" markings located adjacent to the lugs for items weighing more than 150 pounds • Handles, lugs, and other handling gear should be permanent parts of the item's case

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2

*Energy Efficiency Strategies in Urban Planning of Cities**

2.1 Introduction

As discussed in Chapter 1, the world's energy consumption in 2011 was 14,092 Mtoe; about 30 Giga metric tons of CO_2 emissions were released in the atmosphere to meet this energy demand [2]. Greenhouse gas (GHG) emissions and energy demand have risen high on the global environmental agenda—particularly with the Kyoto Protocol and other related global agreements. Consequently, an urgent need has arisen for the incorporation of energy efficiency issues into urban planning and construction [3]. To meet the urban challenges of today, and the challenges to come, appropriate planning strategies and management frameworks must be available, through which cities can apply innovative approaches suitable for their local circumstances. This chapter will review the challenges that cities face and factors that affect new strategies for urban planning where energy efficiency is the core issue shaping the city's future.

2.2 Cities and Energy Consumption: The Macrolevel

The city can be seen as an ecosystem comprising five main sub-systems that interact together. These are population sector, employment sector, housing sector, transport sector and urban land sector [4].

2.2.1 Size

Cities vary in size, starting from only 25,000 inhabitants—the number of city dwellers specified by Egypt's General Organization of Physical Planning (GOPP). In Egypt, population size is the main driving force of urbanisation

* Most of this chapter is derived from Khalil [1].

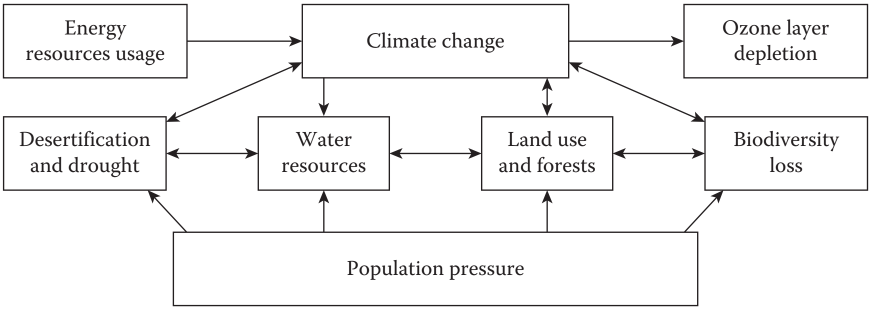

FIGURE 2.1
Relationships among desertification, climate change and biodiversity. (Adapted from The United Nations Economic Commission for Africa (UNECA) and North Africa Office, The fight against desertification and drought in North Africa, *The Eighteenth Meeting of the Intergovernmental Committee of Experts*, United Nations Economic Commission for Africa, Tangiers, Morocco, 2008.)

and in the quest for fulfilling their needs in an urban context. Another dimension related to population pressure in urban contexts is a city's growing size and its impact on climatic change. This is only one part of the environmental chain of energy use, ozone depletion, desertification and biodiversity loss, as shown in Figure 2.1 [5].

2.2.1.1 Mega Growth, Mega Complexity

The megacity is a relatively new form of urban development. In 1950, there were only two cities with populations of more than 10 million: New York and Tokyo. By 1975, two more locations, Shanghai and Mexico City, joined the club. However, by 2004, the number of megacities had rocketed to 22 and, together, these cities now account for 9% of the world's urban population. It is important to note that:

1. Mega cities' importance in the national and global economy is disproportionately high.
2. City governance has to adapt to the challenge of delivering holistic solutions across vast metropolitan regions.
3. City managers must strike the balance between three overriding concerns: economic competitiveness, environment and quality of life for urban residents.

Urban growth is spread unequally around the world, and the same is true of its largest cities. Most of the megacities in the developed world are growing slowly, if at all. Tokyo remains the largest with 35 million inhabitants, but the fastest growth will be in the developing world (particularly in Asia and Africa), placing huge pressure on infrastructure in those locations. By 2020, Mumbai, Delhi, Mexico City, São Paulo, Dhaka, Jakarta and Lagos will each have populations of more than 20 million. Moreover, it is estimated that between 2010 and 2015 some 200,000 people on average will be added to the world's urban population every day with 91% of this increase expected to take place in developing countries [6]. For many emerging cities, soaring populations are extremely difficult to manage; at current rates of growth, the number of inhabitants in Nigeria's Lagos will double by 2020, mainly through expansion of informal settlements. By contrast, most mature cities (as well as many transitional ones) will need to address a different kind of demographic challenge in the form of population ageing.

There is a continuous debate about megacities. On one level, these super-sized cities are seen as the engines of the global economy, efficiently connecting the flow of goods, people, culture and knowledge. They offer, at least potentially, unprecedented concentrations of skills and technical resources that can bring increased wealth and improved quality of life to vast numbers of people. However, megacities also conjure up an altogether darker vision. Most cities in the developing world face huge challenges ranging from congestion and pollution to security threats and inadequate services groaning under the weight of excessive demand. Those in the developing world also struggle to cope with the rapid growth of informal settlements. In 2006, almost one in three members of the world's urban population lives in slums, without access to good housing or basic services [7].

Today's megacities are not only bigger than the cities of the mid-20th century but also more complex. For one, they are increasingly competing with, and dependent on, relationships with other cities in the global economy. At the same time, we are witnessing the emergence of new city regions—sprawling conurbations that extend far beyond the boundaries of a single city. Examples include the 'BosWash stretch' (extending from Boston, MA, to Washington, DC) in the United States, and Chongqing in China. These huge megacity regions create a new urban dynamic. Commuters travel large distances from densely populated suburbs. Economic activity frequently becomes de-concentrated, dissipating from the centre to the periphery. Often fragmented systems of metropolitan governance have not caught up with this trend, with the result that it is difficult to deliver an efficient, holistic approach to infrastructure challenges at a metro regional level [8]. In addition, other new spatial configurations are increasingly taking place, such as urban corridors and city regions. These large urban configurations, as grouped in networks of cities, amplify the benefits of economies of agglomeration, increasing efficiencies and enhancing connectivity. They also generate economies of scale that are beneficial in terms of labour markets, as well as transport and communication infrastructure, which in turn increase local consumer demand [6].

2.2.2 Role and Competitiveness

In the context of continuous globalisation, there is a focus on competitiveness to attract investments to increase cities' prosperity. In this quest, there is a struggle among economic competitiveness and employment, environment and quality of life.

Megacities prioritise economic competitiveness and employment. In a study of which issues drive decision making in 25 megacities around the world, 81% of stakeholders involved in city management cited the importance of the economy and employment. There is a strong focus on creating jobs, with unemployment emerging as the top economic challenge for survey respondents from emerging and transitional cities. Competitiveness in the global economy is another important consideration. Six in ten stakeholders think that their cities place a high importance on making themselves competitive to attract private investment when deciding infrastructure issues [8].

Despite this inclination towards economic competitiveness, development decisions often involve difficult trade-offs between growth and greenness or growth and quality of life. There are obvious interdependencies among the three concerns. Competitive cities are more likely to have the wealth and resources to invest in high-quality infrastructure and services and to create economic and social opportunities for large numbers of the urban population. All things being equal, environmentally clean, modern cities are more attractive locations for a broad spectrum of business activities than those with heavy pollution. Equally, cities with a healthy, well-educated urban population are better positioned to attract investment than those where deprivation and inequality block a large portion of the population from participating in economic growth. This suggests that, in the long run, focusing on one of these concerns to the detriment of the others will be a recipe for failure (as shown in Figure 2.2) [8].

Therefore, cities need modern, efficient infrastructures, especially transportation networks. Abundant (and preferably skilled) labour together with modern information and communications technologies are also hugely important, as evidenced by the offshoring trend that has itself fuelled the growth of cities such as Bangalore in India. Another crucial factor is the

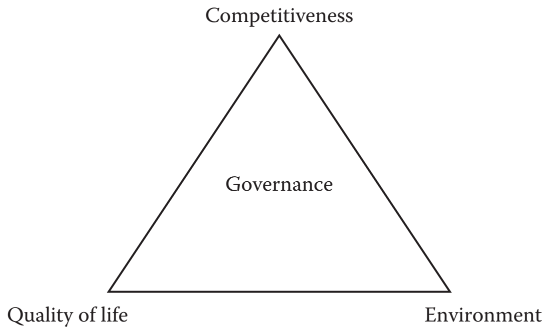

FIGURE 2.2
Striking a balance among quality of life, competitiveness and environment should be the main concern of megacities' governance.

quality of basic services; people with access to quality housing, education and good basic services such as water and electricity are much more likely to fulfil their potential and to contribute to economic growth. The wider business environment is also a key factor; research from the *Economist* intelligence unit indicates that clear, business-friendly policies and regulations are more important factors in attracting international investment than incentives such as subsidies and tax breaks [8].

Whatever their potential, however, many of today's megacities feature a catalogue of environmental problems. Congestion, air and water pollution, waste management and degradation of green areas are familiar issues in most large cities around the world, and they are particularly extreme in the megacities of the developing world. There are also huge inequalities in the distribution of wealth and in economic opportunity among cities. In its recent report on urbanisation trends, UN-Habitat describes cities as 'the new locus of poverty'. World Bank estimates predict that although rural areas are currently home to a majority of the world's poor, by 2035 cities will become the predominant locations of poverty [8].

The consequences of a failure to improve quality of life for the urban poor are huge. The UN-Habitat research indicates that people living in slums, where a large proportion of the urban poor reside, are more likely to be affected by child mortality and acute respiratory illnesses and by waterborne diseases than are their non-slum counterparts. They are also more likely to live near hazardous locations, making them more vulnerable to natural disasters such as floods. Inadequate access to basic services saddles them 'with heavy health and social burdens, which ultimately affect their productivity' [7]. Poverty may be less extreme in the more developed cities, but social problems still abound.

Historically, cities tend to get rich first and then clean up later. Unfortunately, that approach could be disastrous in the context of climate change; this is one reason for the growing focus on sustainable urban development. Sustainable solutions promote greater use of alternative energy sources and more energy-efficient buildings and transport, measures to combat congestion and CO_2 emissions, water and waste recycling, and the use of vegetation to filter pollution and capture carbon dioxide. Although several cities have started implementing at least some of these measures to good effect, there will be a need for more concerted efforts if the environmental cost of urbanisation is to be reduced.

Consequently, it is not growth and economic prosperity that cities should seek; it is rather a more sustainable development that combines efficiency, accountability and environmental responsiveness. This is a goal that comprises the main core of the Sustainable Cities Programme (SCP), a worldwide technical cooperation activity of the United Nations. The SCP works at the city level in collaboration with local partners to strengthen their capabilities for environmental planning and management. Each city-level SCP project is adapted to the particular needs, priorities and circumstances of that city;

nonetheless, all SCP city projects follow the same general approach, and all are implemented through the same series of activities known as the SCP process [9].

The SCP recognises that environmental deterioration is not inevitable. Although many, perhaps even most, cities are still suffering severe environmental and economic damage, there are encouraging signs. Some cities are learning how to better plan and more effectively manage the process of urban development, avoiding or alleviating environmental problems while realising the positive potentials of city growth and change. The SCP aims to support cities in finding—and managing—development paths that are more effectively fitted to their environmental opportunities and constraints.

There is a common approach that is shared by all SCP cities and that holds true across the full range of partner cities [9].

1. Central focus on development–environment interactions
2. Broad-based participation by public, private and community groups
3. Concern for inter-sectoral and inter-organisational aspects
4. Reliance on bottom-up and demand-led responses
5. Focus on process – problem-solving and getting things done
6. Emphasis on local capacity building

More recent initiatives in this field are promoted by various organisations. The Urban Low Emission Development Strategies (LEDS) project, funded by the European Commission and implemented by UN-Habitat and the International Council for Local Environmental Initiatives (ICLEI),* has the objective of enhancing the transition to low emission urban development in emerging economy countries. It offers selected local governments in Brazil, India, Indonesia and South Africa a comprehensive methodological framework (the GreenClimateCities methodology)† to integrate low-carbon strategies into all sectors of urban planning and development. Another initiative is the Cities and Climate Change Initiative (CCCI) that builds on UN-Habitat's long experience in sustainable urban development. The initiative helps counterparts to develop and implement pro-poor and innovative climate change policies and strategies. CCCI also is developing a suite

* ICLEI Local Governments for Sustainability is the world's leading association of more than 1000 metropolises, cities, urban regions and towns representing over 660 million people in 86 countries. ICLEI promotes local action for global sustainability and supports cities to become sustainable, resilient, resource efficient, biodiverse, low carbon; to build a smart infrastructure; and to develop an inclusive, green urban economy with the ultimate aim of achieving healthy and happy communities. Website: http://www.iclei.org

† ICLEI's GreenClimateCities programme offers a process to local governments integrating low emission alternatives into their planning processes and policies. It has a clear methodology, with guidance and/or tools provided for each step. For further information, refer to http://www.iclei.org/our-activities/our-agendas/low-carbon-city/gcc.html

of tools to support city leaders and practitioners in addressing the impact of climate change (adaptation) and to help to reduce greenhouse gas emissions (mitigation) [10].

2.3 Cities and Energy Consumption: The Microlevel

Within planning research, it is commonly assumed that the design and location of residential areas have important consequences for households' energy consumption for housing and transport. It is believed that physical planning and design make it possible to achieve a more sustainable consumption pattern. Mainly there are four distinct consumption categories: energy use for cooling/heating and operating the house; energy use for everyday travel; energy use for long leisure-time travel by plane; and energy use for long leisure-time travel by car.

2.3.1 Urban Pattern

In their study of the relationship between urban planning and energy consumption, Holden and Norland pose the question: Does the change of urban forms tend to reduce the frequency and length of journeys and, hence, energy consumption? To this day, the disagreement persists and the critiques against planning have many different forms, including [11]:

1. Claims that engine technology, taxes on gasoline and driving, and road pricing are more effective measures for reducing energy consumption than urban planning [12,13].
2. The assertion that socioeconomic and attitudinal characteristics of people are far more important determinants of travel behaviour than urban form. Critics in this matter emphasise that the importance of form is highly overestimated in empirical studies [14].
3. Casting doubt on the assumption that proximity to everyday services and workplace will contribute to reduced travel in a highly mobile society [15,16].
4. That the relationship between non-work travel, especially long leisure-time travel, and urban form has been neglected [17].
5. The assertion that travel preferences rather than urban form influence travel behaviour: People live in city centres because they prefer to travel less, and not that they travel less because they live in city centres (the 'self-selection bias') [13].

Even though these aspects should not be taken lightly, there seems to be overwhelming support in the literature for the idea that planning does matter in determining the level of energy consumption in urban areas. This view is based on theory and empirical studies advocating that planning is an important instrument for promoting sustainable development.

2.3.1.1 Compact versus Dispersed Development

When it comes to land-use characteristics that influence energy use for everyday transport, Næss concludes that the following characteristics are favourable for reducing energy use per capita: high population density for the city as a whole; high density within each residential area; centralised settlement within cities and towns (i.e. higher density in the inner part than on the fringe); centralised workplace location; low parking capacity at workplaces; decentralised concentration at the regional level; and a high population for each city [11,18].

The main principle in the compact city theory is high-density development close to or within the city core with a mixture of housing, workplaces and shops. This implies densely and concentrated housing development, which favours semidetached and multifamily housing. Under this theory, development of residential housing areas on (or beyond) the urban fringe, and single-family housing in particular, are banned. Furthermore, central, high-density development supports a number of other attributes that are favourable to sustainable energy use: low energy use for housing and everyday travel, efficient remote heating/cooling systems, proximity to a variety of workplaces and public and private services, as well as a highly developed public transport system.

The supporters of the compact city theory [19–24] believe that the compact city has environmental and energy advantages, as well as social benefits. The list of advantages is remarkably long, including a better environment, affordable public transport, the potential for improving the social mix and a higher quality of life [25]. However, the main justification for the compact city is that it results in the least energy-intensive activity pattern, thereby helping us cope with the issues of global warming. The supporters of the dispersed city suggest that the green city—that is, a more open type of urban structure, where buildings, fields and other green areas form a mosaic-like pattern [11,18].

The list of arguments against the compact city theory is even longer than the list in support of it and includes: that it rejects suburban and semi-rural living, neglects rural communities, affords less green and open space, increases congestion and segregation, reduces environmental quality and lessens the power for making local decisions [11,25].

However, until fairly recently, an international consensus favouring the compact city as a sustainable development approach has dominated the debate [26]. Although there has always been considerable scepticism, the concept of the compact city has been so dominant that it seems inconceivable that anyone would oppose the current tide of opinion towards promoting greater sustainable development and the compact city in particular [27].

Consequently, it is not surprising that the 'move towards the compact city is in the mainstream throughout Europe' [28, p. 275].

The disagreements between the compact city and dispersed city discourses can be summarised to a large extent as a debate about two issues—which form affords the greater energy efficiency, and which aspects of sustainable development are more important?

The relationship between urban form and energy efficiency—especially energy use for travel—is at the core of the sustainable urban form debate. During recent decades, there has been a multitude of empirical studies supporting the relative energy efficiency of the two urban forms. Boarnet and Crane worked through this literature and came to a rather surprising conclusion: 'Very little is known regarding how the built environment influences travel' [13, p. 4]. Although these authors were referring to the United States, we find the same scepticism in Europe. Williams et al. conclude that 'A great deal still needs to be learnt about the complexity of different forms and their impacts' [29, p. 335]. This includes the relationship between urban compactness and travel patterns. A possible relationship between the built form and long leisure-time travel by car and plane is a part of this new knowledge that has to be learned [11].

The possible impacts of urban forms are not limited to travel behaviour. The built form also influences social conditions, economic issues, environmental quality and ecology within the city [29]. All these aspects are also important parts of the sustainable development concept and therefore can be used as criteria for a discussion about sustainable urban form. It should come as no surprise that a study that has minimising energy consumption as an overall goal could easily reach different conclusions from those of a study that aims at using urban form to 'reduce the number of people exposed to fine particles' or to 'promote social equity'. In the end, it will be necessary to balance these impacts because sustainable urban form is ultimately about values [30].

The dispute between the two camps has led to the development of a number of middle positions, which try to combine the best aspects of the compact and the dispersed city discourses, while at the same time trying to avoid the disadvantages of each. Among such alternative middle positions are the urban village [31,32], 'New Urbanism', the sustainable urban matrix [33], transit-oriented development [13], smart growth [34] and decentralised concentration [35–37], and sustainable urbanism [38]. These alternatives all try to combine the energy efficiency gained from a compact urban form with the broader quality-of-life aspects gained from the dispersed city. Still, whether a specific urban form will be more energy efficient is an empirical question [11].

2.3.1.2 Density

Much of the concern with density in planning and other related fields has been over high urban density and its assumed negative effect on the quality of life of urban residents. The city has historically been perceived to be a place of overcrowding, noise, dirt, crime, poverty, disease and so forth [39–41]. The high density existing in cities during the early period of the Industrial Revolution was seen as one of the major culprits of poverty and disease. As a result, planning controls (in Canada and Great Britain, for example) usually specified maximum densities. The planning reaction was a strong movement towards lower density housing outside of the city. In the United States and Canada, this took the form of a move to the suburbs, but in Great Britain and Sweden, it resulted in garden cities [41,42]. Radberg describes the garden city movement as representing decentralised urban growth [39]. The assumption was that these relatively low-density residential areas would not suffer from the ills found in high-density cities and would offer a higher quality of life to residents [43].

More recently, there have been many second thoughts on, and strong criticisms of, these trends. Environmentalists express concern about the environmental implications of low density [44], and urbanists are concerned about the decline of the city [19,40] or of the community [45,46]. Questions about low densities also have been posed by those who are concerned about the efficient use of land and public services [40]; by feminists and researchers who argue that low-density suburbs are hostile to women's lives—especially employed women with children and single parents [47] and by sociologists who criticise the social homogeneity and the social segregation in these low-density areas [46,48]. There are some, of course, who mention all of these problems [43,49].

In 1994, a detailed set of principles were set out in *Sustainable Development: The UK Strategy* (Department of the Environment 1994a), which was subject to further revision in 1999 (*UK Government's Strategy for Sustainable Development* 1999). In this strategy, the land-use planning system was targeted for specific treatment and the foundations laid for more recent policy statements on car usage and urban layouts [50]:

> (24.20) Urban growth should be encouraged in the most sustainable settlement form. The density of towns is important. More compact urban development uses less land …
>
> The scope for reducing travel, especially by car, is dependent on the size, density of development, and range of services on offer …
>
> (24.26) Town and city centres must incorporate the best principles of urban design …

Indeed, the commission recommended that planning guidance should increasingly reflect the growing sustainable agenda and should become much more integrated with other public policy areas, notably economic policy [49].

Hitchcock [51] and Orchard [52] direct attention to the fact that, on the whole, the discussion about increasing density and reducing urban land consumption concentrates almost totally on residential densities. It neglects all of the other land uses that make up a city, even though these land uses represent a significant proportion of a city's total land area. If these non-residential land uses are not taken into account, the reduction in land consumption achieved by increasing residential density will not be as great as initially conceived because services and amenities will have to be augmented to accommodate the increased population [43].

There are a number of advantages from increasing densities, which can be summarised as follows [43]:

1. It can help protect agricultural land from urbanisation.
2. It results in less depletion of the natural resources needed for construction purposes [53].
3. Built forms that facilitate higher net densities may result in significant reductions in energy demands [15,54]. Energy use within buildings can be reduced by passive solar architecture, superior insulation and energy-saving technology [54] or by built forms with low-surface areas and combined heat/cooling and power systems [55]. Owens [15] notes that very different densities (ranging from 37 to 250 dwelling units per hectare) are attainable using combined heat and power systems, depending on discount rates and fuel prices.
4. Decreased pollution from vehicle exhausts can be achieved as a result of a decline in the use of cars, the mixing of land uses, the provision of efficient and accessible public transportation, and walking [15,54]. High densities have been found to be associated with lower gasoline consumption per capita [35,56]; however, this is a controversial issue [28,52,57].
5. Decreased emission of pollutants may result from energy-saving land-use plans and from energy-efficient buildings [53].
6. High density may result in a decrease in the total number of car trips [53]. Nasar found lower automobile dependency scores in high- versus low-density neighbourhoods [58]. These differences were greater for older people, women and households with no children. A decrease in the number of kilometres per trip may also result [54,59–61].
7. High density has been found to be related to a higher proportion of travel on public transit, to greater public transit service provision per person and to transit use by a higher proportion of workers [20,35]. Increased public transit use, in turn, may reduce pollution emissions (an environmental advantage).
8. High density enhances the opportunity to use public transportation because high density brings the development of public transportation systems to the thresholds of profitability and efficiency. The report prepared by Berridge Lewinberg Greenberg, Ltd. adopts several benchmarks for the relationship between residential density and transit use. It suggests that 17–75 dwelling units per net hectare are necessary to sustain significant transit use, and 150 dwelling units result in a modal split of different transportation types in which more than 50% are public transit [62].

9. As a result of an increase in transit use, traffic congestion in residential, work and commercial centres may decrease [62].
10. Public transit can be more energy efficient. Handy highlights that it is the set of choices correlated with density—not density itself—that shapes travel behaviour [63]. In this context, Bannister discusses the interaction between socioeconomic circumstances and people's propensity to travel with different frequencies, trip lengths and transportation modes [59]. Moreover, gender should be added to these intervening variables [64]. Self debates the effect that a change in density would make. He claims, for example, that a 50% increase in the density of Canberra, Australia, would produce only a modest increase in public transit use [65].
11. It offers more opportunities to walk or ride a bicycle to work, service and entertainment facilities [59,60].
12. High densities may result in economies of scale that facilitate the use of better quality and more attractive building materials [51].
13. It enables the use of a building complex as an element of the urban composition. It also allows for a variety of densities and types of construction in a given region. Variation in density and construction, in turn, makes the environment more interesting [51].
14. High-density development in the proximity of public transportation lines can decrease the demand for land located further from these lines [66].
15. High-density development as infill in existing areas can revitalise those areas and can reduce the pressure to develop open spaces [61].

On the other hand, urban density is a major factor that determines the urban ventilation conditions, as well as the urban temperature. Under given circumstances, an urban area with a high density of buildings can experience poor ventilation and strong heat island effect. In warm-humid regions, these features would lead to a high level of thermal stress of the inhabitants and to increased use of energy in air-conditioned buildings. However, it is also possible that a high-density urban area, obtained by a mixture of high and low buildings, could have better ventilation conditions than an area with lower density but with buildings of the same height. Closely spaced or high-rise buildings are also affected by the use of natural lighting, natural ventilation and solar energy. If not properly planned, energy for electric lighting and mechanical cooling/ventilation may be increased and application of solar energy systems will be greatly limited [67].

2.3.2 Land-Use Distribution and Home–Work Trip

The distribution of uses over the city plan is the main driving or restraining force of transportation. It is those trips made to different facilities that shape our daily activities, whether going to work, or using educational, health or other public services, or just for leisure. Housing location influences the distances to different types of facilities, and the spatial location of most of these facilities suggests that average travel distances will be shortest for inner-city residents. However, there are claims that high accessibility to different services might create an increased demand for transport. Moreover, opting for a wider range of jobs, shops and leisure activities might establish the need for more everyday travel.

2.3.2.1 New Urbanism and Transit-Oriented Development

In urban design literature, the development of what is loosely referred to as 'New Urbanism' applies a raft of sustainable objectives to new urban layouts. The evolution of this movement may be traced to the development of urban villages (in the UK) and sustainable growth management projects, also known as New Urbanism (in the United States), that have been 'directed toward creating an alternative to the typical car-dominated suburban sprawl that predominates on the fringe of virtually all western cities and towns' [68, p. 207].

The main design concept in New Urbanism is the creation of a 'module' or 'ped-shed' (walkable urban design and sustainable place making). It is made up of a walkable neighbourhood with a 400-m radius to shops, services and transport nodes in which the fabric creates a series of interconnected pedestrian friendly streets. It does not necessarily ban the private car; however, it serves to 'maximize interaction while minimizing the travel needed to do it' [68, p. 209]. The logic is that there will be a dramatic reduction in car parking provision. It decreases from the predominant post-war patterns of two or three spaces per dwelling to one space or less. Consequently, a link is established between reduced car parking standards and the design of mixed uses, small street blocks and interconnected streets [69]. At a more fundamental level, conventional Western post-war car parking layouts are challenged by the need to raise residential densities to make for greater land-use efficiencies [70] and to foster non-car-based trip generation where a provision of less than one space per dwelling is a desirable objective [71]. Morris and Kaufman acknowledged that this focus on New Urbanism will make a significant contribution to achieving more sustainable cities, yet they voiced concern that 'While the intentions and potential to re-shape cities and towns towards less car dependence is a strong thrust of many practitioners of new urbanism, the evidence of major gains on the ground is limited' [68, p. 208].

The two approaches, New Urbanism and transit-oriented development, do not target increasing densities—any increase in density that is achieved is basically a by-product of a minimal nature. The emphasis of the New Urbanism movement is on small towns. New urbanists envision towns or neighbourhoods that are compact, mixed use and pedestrian friendly [42]. The emphasis of transit-oriented development, whose principal proponent is Calthorpe [49,72], is to plan balanced, mixed-use areas with a simple cluster of housing, retail space and offices within a one-quarter mile walking radius of a light rail system. The motivation for transit-oriented development is to improve the ills brought about by dependence on the automobile and the mismatch that exists between old suburban patterns and the post-industrial culture. The goal is to preserve open space and reduce automobile traffic without necessarily increasing density. Calthorpe [73] defines average net residential densities of urban transit-oriented developments as 44 dwelling units per hectare, with densities of 62–123 units per hectare for up to three-story apartment buildings [43,72].

2.3.2.2 Long-Distance Leisure Time Travel: Compensatory Travel?

An important question that arises from looking at the wider issue of energy use and greenhouse gas emissions is whether, for certain income levels, reduced local everyday travel will be compensated for by increased long-distance leisure travel at other times. Is it the case that—for certain income levels—the sum of 'environmental vices' is constant and that households managing on a small everyday amount of transport create even heavier environmental strain through, for instance, weekend trips to a cottage or long-distance holiday trips by plane? In the professional debate, some [73] have claimed that people living in high-density, inner-city areas will, to a larger extent than their counterparts living in low-density areas, travel out of town on weekends—for instance, to a cottage—in order to compensate for the lack of access to a private garden. In addition to this 'hypothesis of compensation', others, including the Swedish mobility researcher Vilhelmson [74], have launched a 'hypothesis of opportunity', which asserts that the time and money people save due to shorter distance daily travel will probably be used for long-distance leisure-time travel [11].

A study conducted in Norway suggested that the total energy use decreases as density reaches a certain point, although the data indicate that the total energy use increases at higher density levels. This pattern is similar to a pattern in the relationship between energy use and city size found by a number of empirical studies of cities in Norway, Sweden and England [18]. According to these studies, up to a certain point, energy use per capita decreases as density increases, but thereafter energy use starts to increase. Thus, the advantages of 'megacities' or 'extreme density areas' seem to be outweighed by the advantages offered by more modest forms of urban compactness [11].

2.3.3 Road Network and Transportation Network

Transportation is the leading consumer of energy and fuel in the city. The spread of roads among extended urban areas has helped people easily commute within these vast areas, thus making distances irrelevant and promoting more and more dispersion.

2.3.3.1 Road Network

The road network connects the various parts of the city and connects the city with its surrounding context. Thus, it contributes to the efficiency of the city, the flow of people and goods, and consequently to the economic cycle.

However, the emphasis on road network design has created not so lively neighbourhoods. This was expressed by The Prince's Foundation when examining 'Sustainable Urban Extensions' in the UK, in which the problem is summarised thus:

> House builders place a high priority on complying with rules and guidance on highway engineering. They are anxious that their estates' street system should be adopted by the local authority with the minimum of negotiation and delay. Estates are consequently designed around road layouts based on loops, dead-end spines and cul-de-sacs, whose principal aim is to handle road traffic as efficiently and safely as possible. But as well as discouraging travel on foot or by bicycle, these 'roads first–houses second' designs can damage the harmonious grouping of houses and visual quality…. [75, p. 1]

2.3.3.2 Transportation

Because a compact city strategy is recommended to be adopted, an emphasis on the development of rail transport of great accessibility, safety, sustainability and environmental friendliness is the main target. In a study conducted in 25 megacities, the following was found [8]:

1. Transportation is seen as the single biggest infrastructure challenge by a large margin and is a key factor in city competitiveness.
2. With air pollution and congestion emerging as the two top environmental challenges, stakeholders predict a strong emphasis on mass transit solutions.
3. Cities are more likely to focus on incremental improvements to existing infrastructure, rather than on new systems.
4. Demand management is rarely mentioned as a major strategy for addressing the cities' transport problems.

2.3.3.3 Parking

Parking policy is commonly viewed as a complementary measure to reduce car use when combined with other initiatives. Sustainability seeks to establish less reliance than previously existed on private car usage—for example, by promoting compact urban development in areas well served by good public transport. Urban design policy promotes a departure from the 'roads first, houses later' philosophy (as dictated by many highway standards) to give precedence to the relationship among buildings rather than strict adherence to predetermined road design in new residential environments. A new design approach to car parking has emerged where there is a shift from the previously adopted orthodoxy of minimum standards to maximum ceilings (i.e. no more than one space per dwelling). Such a trend towards reduction of parking standards (and thus provision) is at variance with the projected growth in car ownership worldwide [50].

Research studies clearly demonstrate that a trade-off exists between relaxing current car parking standards and raising residential density [70,76]. Urban design commentators and practitioners increasingly lobby in favour of a 'car-free urbanism' in which the sustainable residential neighbourhood is based on radical rethinking of density and parking policy. The avoidance of inflexible standards will yield improved layouts, so that urban design can reclaim the city back from the car [77].

2.3.4 Buildings: Form, Height and Facade Treatment

Globally, buildings are responsible for approximately 40% of the total world annual energy consumption. Most of this energy is for the provision of lighting, heating, cooling and air conditioning [67].

One way of reducing building energy consumption is to design buildings that are more economical in their use of energy for heating, lighting, cooling, ventilation and hot water supply. Passive measures, particularly natural or hybrid ventilation rather than air conditioning, can dramatically reduce primary energy consumption. However, exploitation of renewable energy in buildings and agricultural greenhouses can also significantly contribute towards reducing dependency on fossil fuels. Therefore, promoting innovative renewable applications and reinforcing the renewable energy market will contribute to preservation of the ecosystem by reducing emissions at local and global levels. This will also contribute to the amelioration of environmental conditions by replacing conventional fuels with renewable energies that produce no air pollution or greenhouse gases. The provision of good indoor environmental quality while achieving energy and cost-efficient operation of the heating, ventilating and air-conditioning (HVAC) plants in buildings represents a multivariant problem. The comfort of building occupants is dependent on many environmental parameters including air speed, temperature, relative humidity and quality in addition to lighting and noise. The overall objective is to provide a high level of building performance (BP), which can be defined as indoor environmental quality (IEQ), energy efficiency (EE) and cost efficiency (CE).

IEQ is the perceived condition of comfort that building occupants experience due to the physical and psychological conditions to which they are exposed by their surroundings. The main physical parameters affecting IEQ are air speed, temperature, relative humidity and quality. EE is related to the provision of the desired environmental conditions while consuming the minimal quantity of energy. CE is the financial expenditure on energy relative to the level of environmental comfort and productivity that the building occupants attained. The overall CE can be increased by improving the IEQ and the EE of a building [67].

Urban planning has a considerable impact on the future EE of buildings, and planners lack useful tools to support their decisions. A study was made presenting a new method based on a genetic algorithm that is able to search for optimum urban forms in mid-latitude climates (35–50°). Here, more energy-efficient urban forms are defined as those that have high building absorptance in winter and low summer building absorptance. These forms can be designed by choosing among regular tridimensional building geometries with fixed floor space indices, which can be parameterised by adjusting the following variables: number of floors, building length ratio, grid azimuth and aspect ratio on both directions. The results obtained show that adequate urban planning, based on the consideration of the local radiation conditions as a function of latitude, may result in significantly better building thermal performance. In particular, it is concluded that the highest latitudes are more restrictive in terms of optimal solutions: pavilions (cross-sectional square blocks) are the best solutions for latitudes of 50° and terraces (blocks infinite in length) are preferred for 45°. For lower latitudes, all urban forms are possible. In terms of grid angle with the cardinal direction, it is concluded that the angle should stay between –15° and +15°, except for the latitude of 50° where it can ranges from −45° to +45°. For slab and terrace urban forms, the spacing between blocks in the north–south direction should be maximised, quantified by a building-height-to-street-width (aspect) ratio that decreases with the increase of latitude, ranging from 0.6 for a latitude of 35°, to 0.4 for a latitude of 45°. For pavilions, the north–south aspect ratio is independent of latitude and should stay close to 0.7. The pavilion is the urban form that allows for a larger number of floors [78].

Arguably, the most successful designs were in fact the simplest. Paying attention to orientation, plan and form can have far greater impact on energy performance than opting for elaborate solutions. However, a design strategy can fail when those responsible for specifying materials, for example, do not implement the passive solar strategy correctly. Similarly, cost-cutting exercises can seriously upset the effectiveness of a design strategy. Therefore, it is imperative that a designer fully informs key personnel, such as the quantity surveyor and client, about their design and be prepared to defend it. Therefore, the designer should have an adequate understanding of how the occupants or processes, such as ventilation, would function within the building. Thinking through such processes in isolation without reference to others can lead to conflicting strategies, which can have a detrimental impact upon performance. Likewise, if the design intent of the building is not communicated to its occupants, there is a risk that they will use it inappropriately, thus compromising its performance. Hence, the designer should communicate in simple terms the actions expected of the occupant to control the building [67].

2.3.5 Renewable Energy

Research into future alternatives has been and is still being conducted to solve today's complex problems such as the rising energy requirements of a rapidly and constantly growing world population and global environmental pollution. Therefore, options for a long-term and environmentally friendly energy supply have to be developed that lead to the use of renewable sources (water, sun, wind, biomass, geothermal, hydrogen) and fuel cells. Renewables could shield a nation from negative effects in the energy supply, pricing and related environmental concerns. For many years, hydrogen (for fuel cells) and the sun [for photovoltaics (PVs)] have been considered as likely and eventual substitutes for oil, gas, coal and uranium. They are the most abundant elements in the universe. The use of solar energy or PVs for everyday electricity needs has distinct advantages: avoiding consuming resources and degrading the environment through polluting emissions, oil spills and toxic by-products. A 1-kW PV system producing 150 kWh each month prevents 75 kg of fossil fuel from being mined. It avoids 150 kg of CO_2 from entering the atmosphere and keeps 473 L of water from being consumed. Electricity from fuel cells can be used in the same way as grid power—to run appliances and light bulbs and even to power cars because each gallon of gasoline produced and used in an internal combustion engine releases roughly 12 kg of CO_2, a greenhouse gas (GHG) that contributes to global warming [67].

Sunlight is not only inexhaustible but also only energy source that is completely non-polluting. The World Summit on Sustainable Development held in Johannesburg in 2002 committed itself to 'encourage and promote the development of renewable energy sources to accelerate the shift towards sustainable consumption and production'. Accordingly, it aimed at breaking the link between resource use and productivity. This can be achieved by the following:

1. Trying to ensure economic growth does not cause environmental pollution
2. Improving resource efficiency
3. Examining the whole life cycle of a product
4. Enabling consumers to receive more information on products and services
5. Examining how taxes, voluntary agreements, subsidies and regulation and information campaigns can best stimulate innovation and investment to provide cleaner technology

Until 2002, renewable energy contributed as much as 20% of the global energy supply worldwide [79]. More than two-thirds of this came from biomass use, mostly in developing countries, some of it unsustainable. Yet, the potential for energy from sustainable technologies is huge. On the technological side, renewables have an obvious role to play. In general, there is no problem in terms of the technical potential of renewables to deliver energy. Moreover, there are very good opportunities for Renewable Energy Targets (RETs) to play an important role in reducing emissions of GHGs into the atmosphere, certainly far more than have been exploited so far. However, there are still some technical issues to address in order to cope with the intermittency of some renewables, particularly wind and solar. Yet, the biggest problem with relying on renewables to deliver the necessary cuts in GHG emissions is more to do with politics and policy issues than with technical ones [79]. For example, the single most important step governments could take to promote and increase the use of renewables is to improve access for renewables to the energy market. This access to the market needs to be under favourable conditions and, possibly, under favourable economic rates as well. One move that could help, or at least justify, better market access would be to acknowledge that there are environmental costs associated with other energy supply options and that these costs are not currently internalised within the market price of electricity or fuels [67].

Renewables are generally weather dependent and as such their likely output can be predicted but not controlled. The only control possible is to reduce the output below that available from the resource at any given time. Therefore, to safeguard system stability and security, renewables must be used in conjunction with other, controllable, generation and with large-scale energy storage. There is a substantial cost associated with this provision.

The recent REN21* report (2014) states that renewables have entered the mainstream as we begin the Decade of Sustainable Energy for All (SE4ALL),† mobilising towards universal access to modern energy services, improved rates of EE and expanded use of renewable energy sources by 2030. In 2012, renewable energy provided an estimated 19% of global final energy consumption, and it continued to grow in 2013. Of this total share in 2012, modern renewables accounted for approximately 10%, with the remainder (estimated at just over 9%) coming from traditional biomass. Heat energy from modern renewable sources accounted for an estimated 4.2% of total final energy use; hydropower made up about 3.8%, and an estimated 2% was provided by power from wind, solar, geothermal and biomass, as well as by biofuels. The combined modern and traditional renewable energy share

* REN21 is the global renewable energy policy multi-stakeholder network that connects a wide range of key actors. REN21's goal is to facilitate knowledge exchange, policy development and joint action towards a rapid global transition to renewable energy.

† The UN Secretary-General's initiative Sustainable Energy for All mobilises global action to achieve universal access to modern energy services, double the global rate of EE and double the share of renewable energy in the global energy mix by 2030. As the newly launched Decade for Sustainable Energy for All (2014–2024) unfolds, REN21 will work closely with the SE4ALL Initiative towards achieving its three objectives.

remained about level with 2011, even as the share of modern renewables increased. This is because the rapid growth in modern renewable energy is tempered by a slow migration away from traditional biomass and a continued rise in total global energy demand [80].

It is useful to codify all aspects of sustainability, thus ensuring that all factors are taken into account for each and every development proposal. Therefore, with the intention of promoting debate, the following considerations are proposed [67]:

1. Long-term availability of the energy source or fuel
2. Price stability of energy source or fuel
3. Acceptability or otherwise of by-products of the generation process
4. Grid services, particularly controllability of real and reactive power output
5. Technological stability, likelihood of rapid technical obsolescence
6. Knowledge base of applying the technology
7. Life of the installation—a dam may last more than 100 years, but a gas turbine probably will not
8. Maintenance requirement of the plant

However, the improved energy performance of cities from these kinds of initiatives is usually being outweighed by the increases in the use of fossil fuels by private transports that have occurred in recent years. This is the case all over the developed world, and particularly in the United States and Australia, where low-density urban sprawl has made it very difficult to introduce energy-efficient public transport systems. In cities with low-density sprawl where most people rely on private cars, it will be particularly important to introduce new transport propulsion such as fuel cell technology to make private transport and public transport less polluting and more energy efficient [81].

Really significant breakthroughs in urban EE and introduction of sustainable energy systems in cities will emerge only as a result of major changes in national energy policy. We have seen some significant breakthroughs in some countries, but far more needs to be done to transform our cities from fossil fuel junkies to sustainable, future-proof systems [81].

Thus, in order to reach a sustainable environment, a combination of policies and actions is essential (as proposed in Figure 2.3). These policies include sustainable energy production and renewable energy production as considerations for city planning regarding EE. When these policies are combined with trends in users' consumption patterns, a sustainable environment can be reached.

It is important to note that the know-how exists to decrease urban energy use by 50% or more without significantly affecting living standards, while

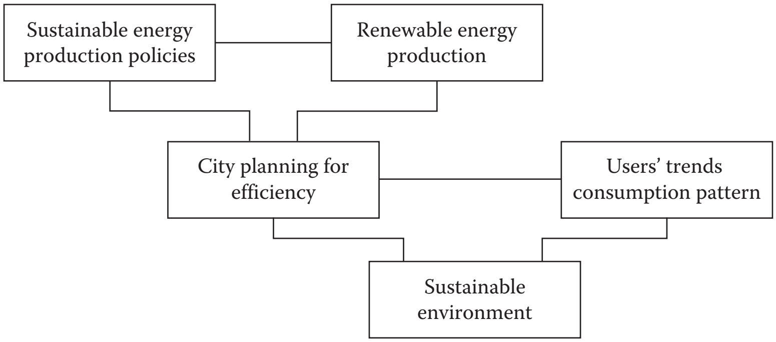

FIGURE 2.3
The relationship among policies for achieving a sustainable environment.

creating many new local jobs at the same time. There are some initiatives to improve the EE of cities—for example, The Cities for Climate Protection Program of the ICLEI. This is a performance-oriented campaign, started in 1993, offering a framework for local authorities to reduce global warming and waste gas emissions all over the world. This framework includes five performance milestones (which were implemented by 500 local governments participating in the campaign in 2004) [82]:

1. Conduct an energy and emissions inventory and forecast
2. Establish an emission target
3. Develop and obtain approval for the local action plan
4. Implement policies and measures
5. Monitor and verify results

2.4 City Consumption and City Impact

2.4.1 Ecological Footprint

In order to measure a city's impact versus its consumption, a more sophisticated analysis has been developed by Rees that can calculate a city's ecological footprint (EF) [83]. As previously mentioned in Chapter 1, it is based on an ecological understanding of how a city extracts food, water, energy and land from a bioregion (and beyond) and what ecosystem services it requires to absorb its wastes. The total resource use of a city is figured relative to its population, and the resulting calculation allows a per capita footprint of land to be compared to that of other cities [84].

The EF, as previously explained, translates consumption of various types into a common metric—the total area of productive land and water ecosystems required to produce the resources that the population consumes and to assimilate the wastes that the population produces, wherever on Earth that land and water may be located [85]. In calculating the footprint of nations or regions, the different bioproductivities of various land types are taken into account; this is achieved by incorporating equivalency factors, such that the calculated EF is expressed as standardised acres of world-average productivity. EFs quantify humans' overall impact on nature in relation to carrying capacity [86]. In 2000, the average global footprint was 6.25 acres per capita, but there were only 4.8 acres available per person based on the biologically productive area divided by the world population. Hence, we were in a deficit of 1.45 acres per person [86], depleting Earth's natural capital rather than living off nature's interest [87]. According to the Global Footprint Network for 2007, these numbers are 6.7 acres per person as EF per capita worldwide, while the biocapacity for Earth is only 4.4 acres per capita. Thus, the deficit has increased to 2.3 acres [88].

The concept of an EF is now firmly ensconced in the environmental literature and, despite its limitations [89–95], there is considerable support among researchers and environmentalists for the footprint as a clear, unambiguous indicator of human impact on nature that is easily applied [85,93,94,96].

One of the important linkages, that is not often drawn, is between EF, urban density and transport energy. Some commentators have criticised the use of per capita car use and per capita land use as confounding the statistics because population is in both denominators [97,98]. However, if the population factor is removed, then it is possible to look at whether land area (the direct footprint of a city) relates to transport [84].

One inherent weakness of using the EF is that it, like other inventory tools, is intended to measure impact. The EF is not designed look at cause and effect. However, where qualitative data provide insight into decision-making processes and choices, the EF becomes a useful tool for understanding the pathways to different outcomes. Also, the raw data assembled for its calculation could be used for specific questions of importance in planning practice.

In addition, the EF could be used by policy makers as part of the approval process for proposed developments. Rather than restricting development according to standard urban design codes, developments could be classified by a maximum EF. It would be up to developers and designers to plan communities that fall within the assigned EF. Rather than crippling innovation and creativity in urban design through legislation, a maximum assigned EF would foster new ideas and designs to tackle the sustainability challenge [87].

A study on the EF in EcoVillage at Ithaca, New York (United States), found that consumption, not built form, contributes most to the overall footprint;

therefore, the link between design and behaviour is of critical importance. The experiences at EcoVillage at Ithaca suggest that physical design may be a catalyst or facilitator of some changes in consumption, especially as they relate to utilities and possibly also to transportation, but no overall conclusion on the interaction between design and behaviour can be drawn from this study [87].

2.4.2 Sustainability Assessment

The EF helps when assessing development on the global scale, but on the local scale there is a need for a much more comprehensive tool. A key aspect to sustainability assessment is the assistance it provides to complex, controversial urban policy issues. One example is the density of cities and planned developments—a very controversial policy area in some urban settings. There is a strong global economic rationale for redeveloping car-dependent cities into focused centres and corridors to make better use of infrastructure at the scale required to provide such local services as public transport, shops and community services within walking distance. The lesser need for transport, the reduced urban sprawl and EF, the far greater opportunities for housing diversity, and other equity issues all provide additional justification at local and global levels. However, those local residents in the area where redevelopment is planned often perceive it as a threat to their local environment and social amenity. Sustainability assessment of such development can ensure there are real global economic, environmental and social benefits (often regional benefits but they may as well be global for many local people), but it can also ensure that developers include real local economic, social and environmental benefits. It can be used to ensure that there is a clear rationale for any development in terms of local environmental benefit (enhancing the local sense of place) and of local socioeconomic benefit (clear provision of better services). With these in place, the local and global issues can be seen to be resolved and a net benefit provided [84].

'Good' planning begins with an assessment of users' needs [99]. For example, transit stops are located in a way that is sensitive to demand. However, planning may also help to shape demand. Indeed, the very existence of planning reveals some general level of acceptance that land markets require guidance to ensure the provision of needs but in a sustainable manner. There are a number of arguments against sprawl; in some cases, suburban development has devoured many wetlands, with consequences for future water quality and supply [100,101], while in other parts of the world it has engulfed arable land. Auto-dependence and associated air pollution have severe implications for those with respiratory problems, and carbon dioxide emissions may contribute to climate change with unforeseeable consequences [87].

Cities will always be centres of consumerism. However, we can change the way they utilise resources. This can be done by conceptualising cities as sustainable ecotechnical systems, which requires converting their largely linear resource throughput into circular resource flows. EE, resource productivity, and urban and industrial ecology are key terms in this context [78].

2.5 Roles of Stakeholders in Planning for EE

2.5.1 Legislations and Laws Addressing Environmental Issues

In order to achieve more energy-efficient cities, where development is sustainable and environmentally responsive, laws and legislations should play a vital role. In 2000, the city of Barcelona introduced its mandatory 'solar ordinance'. All new housing, offices, restaurants, and public buildings have to install solar hot water systems if they use substantial amounts of hot water. Old buildings also have to be fitted with solar hot water systems when they are refurbished. Around the Mediterranean, use of solar hot water systems has become commonplace. In Japan, about 10% of all dwellings have their own solar hot water systems [81].

In German cities, solar PV panels are becoming commonplace, despite the country's relatively cloudy skies. This is primarily due to the German government's 'feed-in' legislation, which has fixed subsidies and favourable tariffs for owners of PV roofs. They used to be paid about 50 cents/kWh for selling their electricity back to the electricity grid, which is about four times the price paid to conventional electricity generators. The policy has led to a massive growth in demand for solar PV technology across the country. Similar policies have been introduced in Austria, France and Spain [81].

2.5.2 Governance

Better governance is a vital step towards better cities. With so many areas crying out for investment in better infrastructure, it is not surprising that funding emerges as a big issue for many stakeholders in a study survey done on megacities.* However, for those involved in city management, it is improvements to governance—rather than just money—that are the top

* A unique global research project undertaken by two independent research organisations, GlobeScan and MRC McLean Hazel, with the support of Siemens, the infrastructure provider. The goal of the project was to carry out research at the individual megacity level to gather objective data as well as perspectives from mayors, city administrators and other experts on local infrastructure challenges. The findings are based on an in-depth survey of over 500 megacity stakeholders, including elected officials, public- and private-sector employees, and influencers such as academics, NGOs and media. This survey was supplemented with extensive secondary research, to enable the team to shed light on the key challenges faced by global cities at various stages of development.

priority going forward. More than half of respondents with knowledge of urban management see improved planning as the priority for solving city problems, compared with only 12% that prioritise increased funding. In addition to more strategic planning, there is also a strong focus on managing infrastructure and services more efficiently. Both these goals will require cities to make the step from passive administration of existing services to a more active style of managing systems that focuses on improved efficiency and more measurable outcomes [8].

There is also a relationship between the scale of the environmental burdens and the appropriate roles of different levels of government. Some governance failures can be traced to a mismatch between the scale of the problem and the scale at which the response has been articulated. Local governance should not be expected to reduce carbon emissions voluntarily, although it can be a very appropriate level for driving local water and sanitation improvements. Global governance, on the other hand, is clearly needed to help develop institutional mechanisms to reduce contributions to global climate change, but it is inappropriate for developing institutional mechanisms for managing local water and sanitation systems. On the other hand, reducing local environmental burdens often requires support (or at least the absence of opposition) from global processes and institutions, while responses to global burdens often need to be rooted in local agency [102,103]. Moreover, cities and their needs are complex, and the traditional, departmentally organised approach to city governance needs to be rethought to enable more holistic solutions on the one hand and more responsiveness and accountability to citizens at a local level on the other [8].

The search for improved efficiency may require megacities to contract out the management of more services to the private sector. One of the more surprising findings in the survey is the fact that the main perceived advantage of private sector operation is improved efficiency (more than access to funding). Where cities do increase private sector involvement, they will need to create the right framework for success. There is a variety of models available, where ownership and operation of services can be shared. But when entering into partnerships with the private sector, the consequences must be well thought through, and success will require a 'context-sensitive' approach to privatisation, with overall control (and responsibility) resting with the public sector. If comprehensive governance models and efficient management structures are put in place, economic attractiveness, environmental protection, and quality of life for all citizens need not be contradictory goals [8].

Today, there is almost universal recognition in governments at all levels that it is essential to incorporate environmental considerations into urban planning and management. This provides significant benefits in every area of urban life, cutting across issues such as health, poverty, security, and economic development. Moreover, there is an essential call for better communication within the government and with other stakeholders involved in city planning and operation.

2.6 The Middle East Context

2.6.1 The Gulf Area

The Gulf area as an arid zone provides a challenge for architects and urban planners to build urban settlements that respond to the needs of inhabitants for climatic comfort and in the same time be sensitive to energy use and its consequences of climate change. This section reviews two approaches to tackle this issue and provide a climatic responsive built environment that is energy efficient.

2.6.1.1 A Return to Compact Cities

Over centuries, the climate in Arabia has become a major factor that shaped the daily life of local societies and, thus, the form of their cities. Old cities were characterised by their compactness, which stemmed from the need for protection from the harsh environment. Urban fabric has been dominated by the building masses, the limited number of enclosed public and outdoor spaces, and the inward-looking architecture. Besides its environmental utility, compactness also provided a physical support to the local community, reflecting its strong social structure and complex network of kinships. Nowadays, Gulf cities that are mostly shaped by the modern movement and American lifestyle are in complete negation with their past. An unprecedented sprawl effect is taking place all over the Gulf countries due to the heavy reliance on private transportation, high building technology, powerful air-conditioning systems and private housing [104].

A study by Ben-Hamouche on cities in Arabia recognised two historical shifts in the form of the city. The first one occurred during the industrialisation era from the old compact city to the modern dispersed city, and the second shift is expected to occur in the information age from the modern dispersed city back to the post-modern compact city through the combination of the concepts of sustainability and IT. He refers to the New Urbanism movement and its principles in his call for referral to compact cities as a remedy to the cancerous sprawl and suburbia [104].

Although this study claims that the information age will make the city more compact, due to the diminishing need for mechanical mobility, this increased accessibility might not lead to compactness. The sprawling may continue; only car usage might decrease but not necessarily increasing density.

2.6.1.2 Masdar City: Innovative Technologies [105]

As the geographical core of the Masdar sustainable energy initiative, Masdar City has been one of the elements to move forward the most quickly. The concept is simple but radical: zero-carbon and zero-waste. This involves a radical rethink of everything about the way that the city will function.

The 7 km^2 site selected is near the airport and about 17 km from the city of Abu Dhabi, and were it not in the desert, it would be classified as a 'greenfield' site. The fundamentals of the plan have been agreed, ground has been broken and phase one is underway. Initially, more than $300 million of procurement is in place, and an additional $1 billion was expected to be committed by the end of 2009. The city was due to be built in 7 years, at a total cost of $22 billion. The first $4 billion of this was coming from the Masdar Initiative, with the remaining $18 billion being raised through direct investments and other financial instruments. In 2013, the Abu Dhabi government has committed $15 billion to Masdar city. Moreover, more than $1 billion of equity has been invested across renewable energy projects with a total value of over $6.9 billion [106].

Sir Norman Foster, the British architect, is behind the design of the city, and detailed planning and preparation has been done by a range of international consultants and experts, including Pooran Desai from BioRegional, the UK consultancy WSP, Canada and United States-based CH2M Hill.

2.6.1.2.1 Building Design

Much of the design will adopt local, vernacular architectural principles, but this will also be mixed with a lot of cutting edge technology, some of it still in the experimental phase. The city will incorporate traditional medinas, souks and wind towers and will make use of open, public squares and narrow shaded walkways to connect homes, schools, restaurants and shops. The buildings themselves will then adopt a wide range of passive measures, and they should consume well under a quarter of the energy used by comparable buildings elsewhere in the region.

2.6.1.2.2 Transportation

There will be no cars in Masdar City—indeed, no internal combustion engines of any type. Instead, there will be a network of electric trams (a light rail transit or LRT system, which will also link to the planned Abu Dhabi LRT system) and smaller, 'personal rapid transit' vehicles, effectively an automatic, driverless system of electric taxis controlled by a central computer. These will be programmed so that, once occupied, the passenger has privacy and no other passenger can board along the route.

2.6.1.2.3 Renewable Energy

All the energy used in Masdar will be renewably generated, not only the electrical power but also that for heating, cooling and transport. The bulk of this is likely to come from one solar form or another. There will be power generation for a smart grid from solar thermal power and concentrating PV and also distributed PV throughout the city. The wind resource in Abu Dhabi is generally poor and will contribute little to the overall mix, but some geothermal and waste-to-energy, particularly from bio waste, are also likely to be significant contributors.

As well as providing a regional location, there are also numerous partnership opportunities for companies with technologies that may be used at Masdar. Among the energy technologies expected to be sourced are PV and solar thermal power generation (concentrating PV, parabolic trough and parabolic dish generation); advanced thermal waste treatment plants; geothermal systems that can be used for district cooling; and smart grid management systems. A range of other district cooling systems are also being considered, together with water desalination and grey-water treatment plants, and waste handling systems, including plasma and pyrolysis. More widely, procurement is also underway for IT systems, the transport infrastructure and facilities management and services.

The Arabic word 'Masdar' was chosen as the name of the project because one definition of the word is 'source'—in the sense of the root or spring from which things originate. For years, many good renewable energy projects have suffered through lack of access to sources of funding. The Masdar Initiative demonstrates that the combination of good projects and a plentiful source of funding can result in very rapid development of even the most ambitious plans. As such, it may also be a beacon for other places that are contemplating whether large-scale investment in renewables really can pay off.

2.6.2 Egypt

There is a growing awareness in Egypt about the change in climate since 1982 when that country established the Egyptian Environmental Affairs Agency (EEAA). Egypt was also one of the first Arab countries to sign the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. Egypt has participated in and undertaken several actions that deal with climate change and environmental issues [107].

1. Ratification of the UNFCCC, the issuance of Law 4/1994 for the Protection of the Environment, and participation in various international workshops and conferences related to climate change to avoid having any international obligations on developing countries, including Egypt.
2. The Ministry of Electricity and Energy has established several projects in the field of new and renewable energy (wind, solar, hydro and bio) and has encouraged EE projects.
3. The Ministry of State for Environmental Affairs has established guidelines for the private sector to encourage investments in the field of clean energy projects, waste recycling and afforestation.
4. With the restructuring of the National Committee of Climate Change in 2007, as the coordinator on the national level related to climate change issues, by putting a visionary for needed policies and

strategies to deal with these issues, and by suggesting mechanisms required for implementation.

5. Maximising the benefit from Kyoto Protocol Mechanisms through implementing Clean Development Mechanism Projects.

An energy code for BP was established by the Housing and Building Research Center (HBRC) in 2006. It specifies the energy consumption of buildings according to their use and typology. This was an initiative to make buildings more energy efficient; however, this code has not been yet implemented.

2.6.2.1 Strategic Planning for Cities Programme

On the urban planning level, since 2008, there have been a lot of efforts made to upgrade more than 200 Egyptian cities. The programme, conducted by the GOPP, started strategic planning of cities under the auspices of the Ministry of Housing. A parallel programme is run and funded by the UN-Habitat concerning small cities (i.e. 25,000–50,000 inhabitants).

It is important to note that continuous urbanisation of rural areas in Egypt has created a unique case. One can find cities that are just villages in their structure, plan, network and physical and social infrastructure. These cities comprise most of the Egyptian urban context. This is primarily due to the way a city is defined by the government (according to population size). Typically, a city is defined as a settlement with more than 25,000 inhabitants. In other words, a village could become a city when its population exceeds this limit; however, it will still hold its rural characteristics, way of life, function and physical features.

In the context of the strategic planning of cities, three main sectors are studied: shelter and informal areas, infrastructure and local economic development. Three other sub-crosscutting sectors are investigated: local governance; environment; and poverty, women & vulnerability. Its main activities include preparing a city profile for the sectors investigated, a list of projects that are required by the city that represent its priorities, and a strategic plan with these projects situated in the appropriate locations that shows the road network, land uses and city limits. All processes are conducted with a participatory approach where all the city stakeholders are involved in the process of planning, prioritising and decision making. The final product is the strategic plan for the city.

The environment sector is mainly concerned with environmental hazards, pollution, noise and solid waste management and recycling. There is no mentioning of energy responsiveness or planning for maximising efficiency of energy use. However, these issues might be tackled depending on the environment consultant concept and the local context of the city under study.

Despite the programme's negligence related to energy responsive strategies, it provides a unique opportunity to really make our cities green and energy responsive. There are a number of ideas and actions that, if gathered and formulated into a strategy, could present a pioneer example within local contexts of the developing world.

In the progress of strategically planning the city of Ashmun in the governorate of Menoufia, Egypt, a number of ideas and requests were submitted by the local community that are energy responsive in essence (Figure 2.4) [108].

1. Preserving city boundaries with minimal increase just to accommodate future needed services and the preservation of agricultural land.
2. The need to build a ring road to increase transportation efficiency and decrease energy consumption and pollution.
3. Increasing the heights to double the street width (law specifies max building height = 1.5 street width) in structurally fit buildings to become four floors instead of only three floors. Thus dandifying existing urban areas instead of horizontal spread of the city.
4. Non-inclusion of sprawling houses in city limits in order to prevent or minimise future expansion on agricultural land.
5. Wise location of needed services, appropriate rates per capita of services and facilities, and their concentration in single location central to community.
6. Advocating mixed uses as commercial/residential uses.

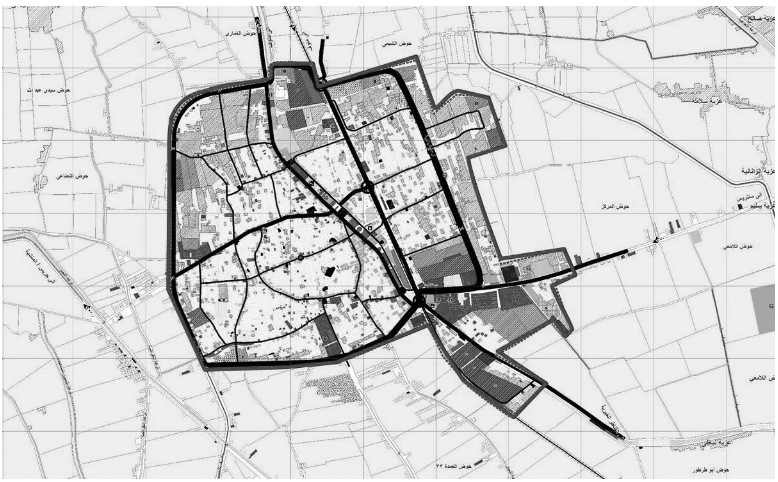

FIGURE 2.4
Keeping Ashmun city boundaries to the minimum and preserving surrounding agricultural land. (From Associated Consultants. (2008). *Strategic Planning for Ashmun City, Menoufia, Egypt*, Ministry of Housing, Utilities & Urban Communities and The General Organization of Physical Planning (GOPP), Cairo, Egypt.)

7. Locating workshops in a special area outside the residential mass, increasing efficiency of operation, management and transportation to other cities for further manufacturing.
8. The need to replace old deteriorated water supply asbestos pipes to prevent leakages and minimise health problems.
9. Better road network linkage with surrounding settlements for better and efficient transportation. Proposing a bridge to decrease travelling distance to neighbouring industrial zone (Sadat city). Thus providing jobs, preventing agricultural land loss and advocating more efficient industrial centres.

These ideas were required and enforced by the local community and the elected leaders, which shows awareness of the pressing issues of energy responsiveness and conventional resources depletion, despite the fact that a direct correlation to EE was not explicit. But this subtle concern can provide a solid base for more action to provide strategies for planning for EE in Egyptian cities.

2.6.2.2 Cairo

The megacity of Cairo is rated second worldwide for its pollution rate (Figure 2.5) [8]. There are approximately 18 million people living in the Greater Cairo region, which consists of five governorates. Expansion has caused many problems related to the environment, quality of life and infrastructure. Cairo is denser than many other cities because the law specifies an allowed maximum density of 150 person/feddan (357 persons/ha); it does not need to become any denser. However, there is a need to revise the current development strategies concerning the sprawling communities around the city. These gated communities are a replica of the American image of the perfect housing environment, where a villa exists on a private piece of land with a front lawn and a back garden. The building density is as low as 25% (downtown can reach 60%–70%) to accommodate for the extended open spaces. These communities were originally part of the green belt designated to surround Greater Cairo. However, there was a shift towards transforming it into dwelling areas, but with low densities, as an attempt to preserve the concept of the green belt.

Although there is a growing demand for these communities, they are far from environmentally friendly. The extension towards the new cities of Sheikh Zaied and 6th of October on one side of Cairo and the cities of Obour, Elshorouk and New Cairo on the other defies the original concept of establishing these as separate cities and transforms them into parts or districts of ever-growing Greater Cairo (see Figure 2.6).

This has really affected energy consumption trends, especially in increasing car dependency. The lack of an adequate transportation system that

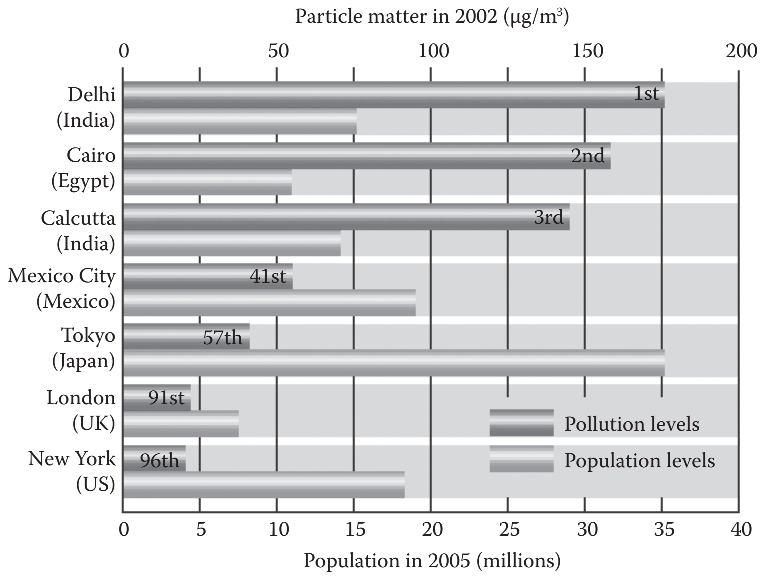

FIGURE 2.5
World's most polluted cities. (From The World Bank as cited in GlobeScan and MRC McLean Hazel, *Megacity Challenges: A Stakeholder Perspective*, Siemens AG, Munich, 2007.)

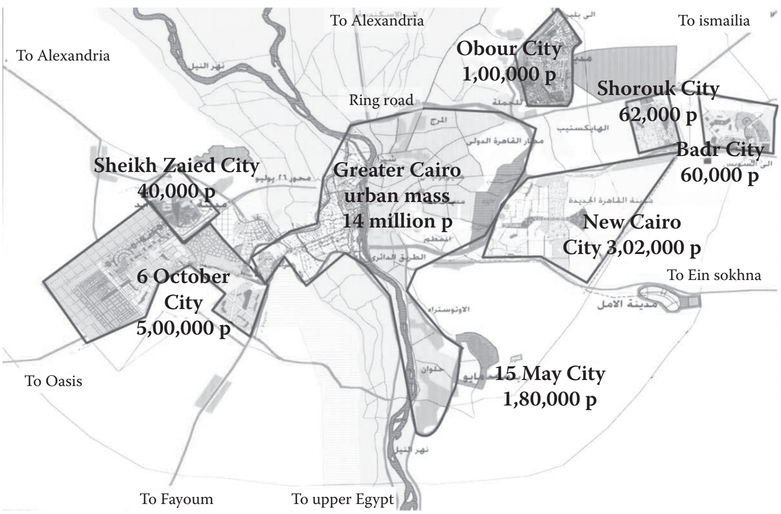

FIGURE 2.6
Greater Cairo with the surrounding new cities.

links all spread-out areas increases car dependency and fuel consumption. The home–work trip is becoming a daily nightmare resulting in congested traffic with a continuous peak hour.

Moreover, these gated communities and nearby new cities lack sub-centres that provide adequate services or businesses. Thus a trip to downtown Cairo is essential for obtaining services.

2.7 Conclusions

In November 2007, UN-Habitat held an Expert Group Meeting on 'Cities in Climate Change' in Nairobi, Kenya, bringing together participants from UN agencies, research institutions, local authorities and the private sector. The experts discussed the role of UN-Habitat regarding climate change and worked out basic elements for the agency's strategy on cities in climate change. The main outcomes of the Expert Group Meeting are that UN-Habitat has a clear role to play in dealing with climate change at the local level with a special focus on urban areas in developing countries. Furthermore, climate change should be regarded as a cross-cutting issue and integrated into UN-Habitat's existing initiatives and programmes [109].

The experts underlined the importance of immediate action—for example:

1. Launching of the Sustainable Urban Development Network (SUDNet) in 2008 for strengthening the performance of local governments to enhance climate change mitigation and adaptation measures in developing countries through existing and new partnerships
2. Promoting city-to-city cooperation
3. Conducting vulnerability assessments and risk mapping at the local level and providing guidelines for adaptive local planning
4. Collecting and sharing case studies on good practice
5. Developing mechanisms to assist cities in preventing land-use conflicts arising from relocation of human settlements
6. Assisting governments in translating National Adaptation Plans of Action to Local Adaptation Plans of Action together with adequate transfer of resources

This is in line with the experience gained from the Strategic Planning for Cities Program in Egypt because the actions required by the experts are what the programme in Egypt lacks on the broad level.

Much can be done in the developing countries. In the Egyptian context, there is a need for more awareness and action with regard to energy-efficient

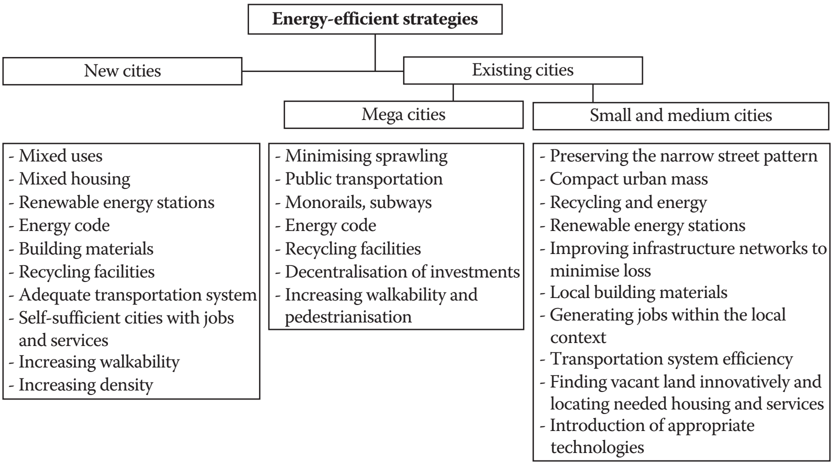

FIGURE 2.7
Energy efficiency strategies in cities.

strategies and to integrating them in urban planning. These strategies are summarised in Figure 2.7. On the personal level, it is recommended to try to use one's car less and separate his garbage as the former mayor of Curitiba, Brazil, advises [81].

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