Chapter 14
Small-Scale System Solutions—Material Flow Management (MFM) in Settlements (Water, Energy, Food, Materials)

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Abstract The complexities of the present energy-climate era coupled with the ambitious targets of the 2030 Sustainable Development Goals (SDGs) demand approaches to resource management that transcend conventional strategies. Material Flow Management (MFM) can be a vital tool in sustainable resource management (SRM) in complex systems. It contributes, among other things, to the protection of land, the conversion of abandoned land and the upcycling of degraded land. Despite its relative novelty, its usefulness has already been demonstrated. This chapter presents the practical application of MFM in small-scale systems, which are characterised by decentralised material and energy flows. It attempts to highlight the utility of MFM in SRM. The chapter gives special attention to the augmentation of source and sink capacity, employing MFM to reduce impacts on ecosystems both upstream and downstream—i.e. on the use of resources as well as on the amount of emissions.

Keywords Material flow management · Regional added value · Potential analysis · Zero emissions campus

14.1 Introduction

14.1.1 Anthropogenic Systems, GDP Growth, and Material Flow Management

Contrary to the (wise) premise, we, "the wise"—or *Homo sapiens,* have always taken an anthropocentric[1] stand toward everything we have done so far. By any reasonable judgement, this will largely stay the norm for the next couple of decades as well.

[1]The view/belief that human beings are the most important entity in the universe. The analysis of Kopnina et al. (2018) may be useful for some insights and perspectives.

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The taming of nature and the extraction/consumption of ever-increasing quantities of resources have been fundamental aspects of all progressive civilisations thus far. It is also fundamental to the current model of economic growth and development that we follow to the hilt. As a consequence, severe environmental degradation and the depletion of resources have occurred in tandem. Adding insult to injury, globalisation and population growth coupled with the fallacious chase for GDP growth have aggravated this situation even further.

However, since the mid-twentieth century, the *manmade* environmental calamities such as the Great Smog of ’52, the threat of DDT in the ’60s, the ozone depletion of the ’70s, and the largest ever oil spill in human history—the Persian Gulf oil spill in ’91—drew humanity’s attention to the underlying issues, prompting a sluggish, nevertheless noticeable shift in this anthropocentric order of business toward an ecocentric direction.

The extensive consumption of fossil resources along with the application of synthetic chemistry/biology—which are also liberally attributed to the aforesaid calamities—has triggered a frenzy of industrial and economic development (see Fig. 14.1: GDP as a proxy indicator), which as a result has increased humanity’s environmental footprint like never before.

Intensive pollution—land, air and water—was widely recognised as a symptom of the underlying societal metabolic disorder; this gave impetus to the global green movement in the twentieth century. Adding momentum, the contemporary debate on global climate change, which is attributed to anthropogenic global warming, has

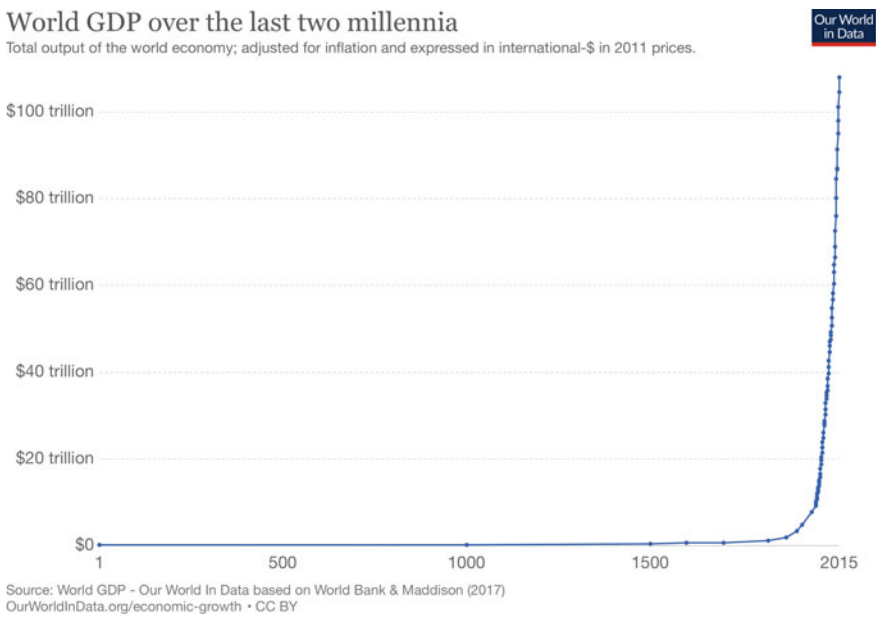

Fig. 14.1 World GDP growth. *Source* Roser (2019)

accelerated the pace of application of *green [environmental] solutions* globally in recent decades.

To create any significant impact, such solutions need applications on different levels and scales. Clearly, anthropogenic systems are complex and come in all shapes and sizes (e.g. a business, a municipality, a political system, the European Union, etc.). Systems are characterised by a system boundary and the flow/flux of material and energy across and within the system boundary. Inputs such as raw materials and energy, and outputs such as products, services and waste/emissions are inherent to anthropogenic systems. These various inputs and outputs further distinguish various systems. In dealing with complex anthropogenic systems, special attention should also be paid to the output of money as a valuable resource, as many of the problems originate from an incorrect allocation of money and the concurrent loss of economic power and opportunities related to financial waste from systems (see Fig. 14.3).

Despite the lack of consensus on the definition of "small-scale systems", in this text, we focus on small-scale political and administrative systems such as villages, municipalities and business entities such as farms, factories, SMEs, etc. Small-scale systems play an important role in rural areas of the world, in particular by provisioning ecosystem services, clean water and healthy food. They also help to conserve biodiversity and facilitate multifunctional land use, etc.

14.1.2 The Throughput Society and the SDGs

Currently, the predominant practice of resource *management* involves extracting, making, using, and wasting/throwing away. This practice is denoted as the throughput system (also known as the throughput metabolism). Accordingly, we can describe present human society as "the throughput society" and the current global economy as "the linear economy". Characteristics of these systems include the massive input/use of virgin resources, low levels of resource productivity/product efficiency, and the generation of gargantuan amounts of emissions or unwanted by-products that are usually termed *waste*. Thanks in large part to this throughput system of resource management, "global primary material use, and thus global primary material extraction, is projected to double in the coming decades… from 79 Gt in 2011 to 167 Gt in 2060" (see Fig. 14.2).[2] From a land use perspective, this foresees a massive increase in the use of valuable land resources for resource extraction, agriculture and urban development, collectively resulting in permanent degradation of ecosystems due to, among other things, the depositing of *waste materials*. From an anthropocentric point of view, ecosystems are *essential* for provisioning (e.g. food and water) and regulatory (e.g. flood control, climate) services. To use them as waste deposits or sinks leads to the loss of (sometimes irreversible) service capacity.

The constant bombardment of news about environmental calamity, resource scarcity, social inequality, economic downturn, etc.—inevitable consequences of

[2]Note: indicates the net effect of the three trends.

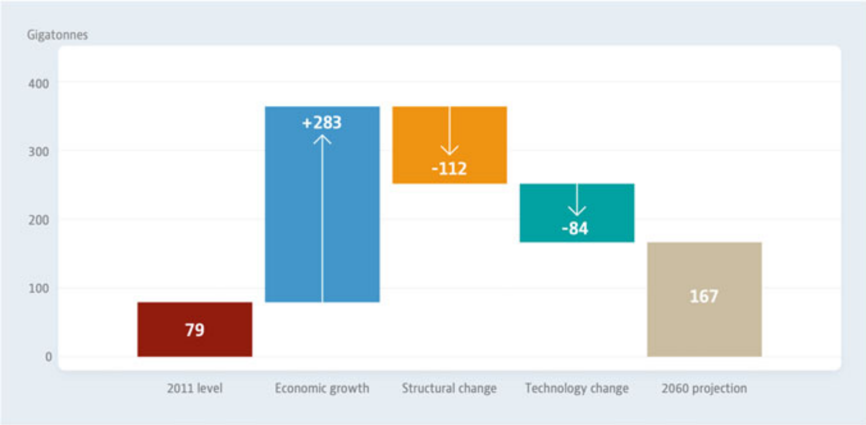

Fig. 14.2 Forecast of global material use. *Source* OECD (2019)

the throughput system—remind us that humanity is facing an existential threat, for which achieving sustainability has been projected as the panacea. It was for this reason that UN policymakers set out to achieve environmental, social and economic sustainability (popularly termed "triple-bottom-line sustainability") as humanity's goal for the current century, employing the Sustainable Development Goals (SDGs) in the short term for the endeavour.

The underlying matrix that forms the objectives of the SDGs also includes the following: achieving social and intergenerational equity, extracting and consuming resources in accordance with the planetary boundaries, and, at the same time, achieving economic growth and prosperity while minimising negative environmental consequences.

Though the exact origin of greening for sustainability is somewhat nebulous, its effects have become increasingly common over time, presenting a broad array of solutions for the aforementioned socioeconomic and environmental concerns. These solutions include green products (e.g. green chemicals) and services (e.g. green IT, green design and green certification); green infrastructure (e.g. green buildings); green energy (e.g. carbon–neutral/renewable energy); green processes (e.g. green manufacturing, green chemistry); green policies (e.g. green public procurement), etc. The goal is to establish green jobs and green cities with the ultimate aim of introducing green economies, where sustainability is the fundamental value.

14.1.3 *MFM and Associated Tools*

The circular economy, material flow management and zero emissions are different aspects of a new nexus in the world. The circular economy is the new paradigm, material flow management is the management tool for implementation, and zero emissions

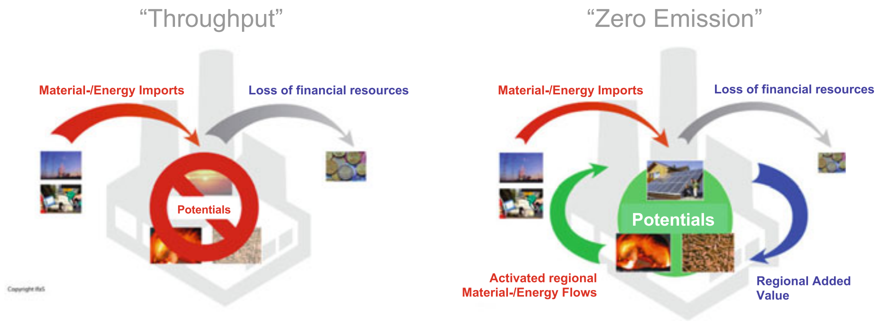

Fig. 14.3 The transformative approach of MFM. *Source* IfaS (2019)

are the ultimate target. "Nexus" in this context emphasises the new holistic view of managing systems as such, instead of optimising individual components in linear flows. Closed-loop economies need to pay attention to embedded energy, virtual water, carbon footprints, levelised costs of service, etc. This segmented view of our society hinders economic efficiency, resource efficiency and emission reduction. As often observed in such an approach, the suboptimal allocation of financial resources also leads to negative incentives for unsustainable investments.

14.1.3.1 Material Flow Management

Material flow management (MFM) strives to change the throughput metabolism and helps users to develop technical and economic alternatives designed to improve the system's conditions and reduce the outgoing material and energy flows—more commonly termed *emissions* or *waste*. MFM could be applied to any typical consumption and production system insofar as its primary goal is to optimise material and energy flows according to given objectives. Figure 14.3 illustrates the material and energy flow of a typical throughput system that, by implementing MFM, circulates resource flows while reducing virgin and non-renewable resource inputs, minimising the loss of financial resources and reducing environmental impacts due to emissions. Ideally, the resulting new system could be a zero-emissions (ZE) system, depending on the targeted objectives.

Typically, material flow analysis (MFA) precedes MFM, during which a thorough system analysis is performed to qualify and quantify the resource flows through and within the defined system boundary temporally and spatially.[3] The MFA not only collects and assesses the pertinent data, but also makes this information visible and transparent. This, in turn, allows policymakers and scientists to simplify and elaborate on the problems and their subsequent management options. Figure 14.4

[3]MFA and MFM proper are the two methodological steps of material flow management. Material flow management is a yet unpublished but often used management strategy developed at ECB by Professor Dr. Peter Heck.

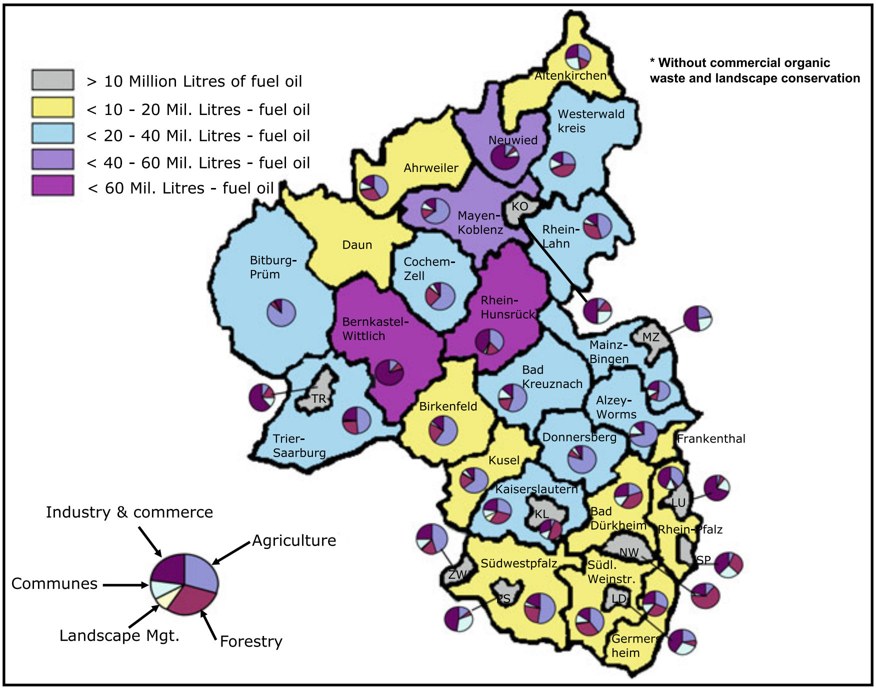

Fig. 14.4 Available biomass potential in the counties of Rhineland Palatinate (Heck and Hoffmann 2001). *Note* The biomass estimates include various sources, such as forestry, landscaping, agriculture and organic household waste. Various conversion technologies such as incineration and digestion have been used to calculate the oil equivalent. Only biomass that is technically and legally available as well as economically viable is shown

shows an analysis of biomass potential in the state of Rhineland-Palatinate. The MFA clearly reveals the enormous potential of biomass, expressed as the availability of oil equivalents per year. In this way, MFA leads to more transparency of systems with regard to their potential. MFA also illustrates the current states of systems (or the status quo), as illustrated in Fig. 14.5.

MFM usually details a comprehensive plan for the specific management and financing of individual projects that optimises specific resource flows; together these projects lead to system change. As mentioned earlier, one ideal system optimisation target could be a ZE system, in which emissions flows are utilised within the system's boundaries or connected to adjacent subsystems as valuable raw material inputs (such as in the case of industrial symbiosis), creating closed loops of material and energy flows—i.e. a *circular* system. This ultimate system state is usually referred to as the circular economy (CE) model (as opposed to the "linear" model of the economy mentioned above), which is environmentally, socially and economically sustainable. Typically, the holistic sustainability results of such an optimised system can be measured in terms of regional added value (RAV). RAV presents/quantifies

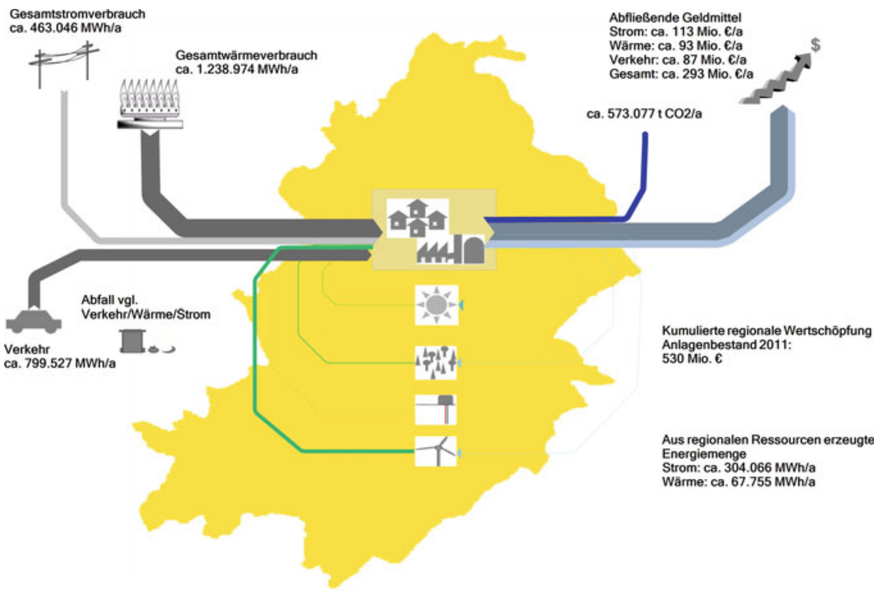

Fig. 14.5 MFA for the Rhein Hunsrück District (IfaS–Heck et al. 2011). *Note* The Sankey diagram shows financial losses (in €/year) and the CO_2 emissions incurred (in t CO_{2e}/year) on the upper left side. The main energy sources are still fossil fuels, as can be seen by the thin green lines for renewable energies and the rather thick black/grey lines for conventional electricity and heat sources

both monetary and non-monetary benefits derived from MFM. Non-monetary benefits include, among others, lower pollution levels, increased biodiversity, improved aesthetics, increased innovation, an enhanced public image, etc. Monetary benefits include increased labour and employment opportunities, increased savings, lower costs, increased revenues from new business ventures, new sales options, etc. As can be seen, the key objective of material flow management (MFM) is to optimise systems in order to achieve more systemic added value, while achieving triple bottom line sustainability.

The starting point of current models of targeted sustainable economies—specifically the circular economy (CE), the bio-economy (BE) and the green economy (GE) as depicted in Fig. 14.6–is the use of MFM and ZE technologies and strategies. Despite the size of the anthropogenic system targeted or the sustainable economic model to be followed, these tools are intrinsic; therefore, here we investigate the concept of ZE and its implications on CE.

14.1.3.2 Zero-Emissions

As remarked on earlier, the throughput society of today extracts ever-increasing amounts of resources from the earth's ecosystems and turns the bulk of it into different

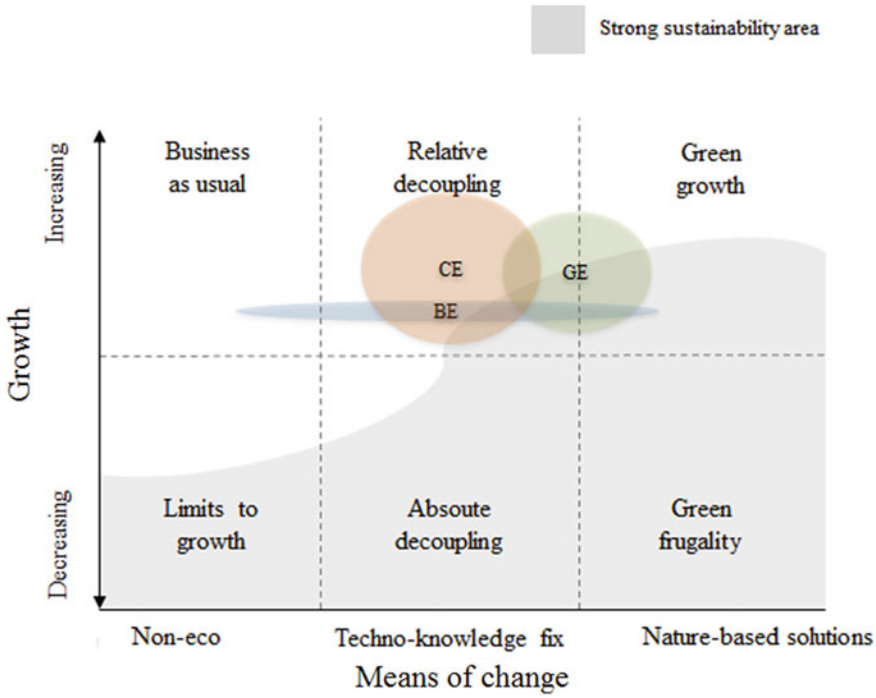

Fig. 14.6 Relative positions and associations of the GE, the BE and the CE. *Note* Fig. 14.6 is intended to highlight the close association and relative position of the three concepts. The size of the bubbles in the figure does not pertain to the current work. Franceschini and Pansera (as cited in D'Amato et al. 2017)

kinds of waste products such as solid waste, wastewater, waste gas, waste heat and greenhouse gases. These create enormous environmental pressures, often with lasting negative impacts. As resources become depleted and sinks become increasingly overloaded, the reduction and/or the avoidance of emissions will be a vital measure to protect resources and sinks, and thus prevent land and ecosystem degradation.

In that context, the approach of zero emissions (ZE) calls for the systemic, overarching optimisation of processes, incorporating elements of sufficiency, efficiency and substitution. Zero emissions do not mean avoiding all emissions as such. Instead, it means avoiding the types of emissions that lead to negative impacts on neighbouring (eco) systems, such as rivers, wetlands, agricultural land, etc. It also stipulates changing system metabolism in such a way that by-products are either upcycled or improved as a result of secondary use options, or drastically reduced in terms of volume. Another key element of the zero emissions strategy is a focus on economics. Avoiding emissions makes economic sense, even without considering externalities. In a world with dwindling resources and shrinking sinks, the efficient use of both could save money and create competitive new business opportunities with better bottom lines. For small-scale, financially strained systems such as rural villages and municipalities, SMEs, etc., a ZE strategy can assist in boosting the local economy and/or cash flow, while reducing the environmental burdens arising from consumption and production systems.

14.1.3.3 The Circular Economy

The CE is an alternative route to holistic sustainability, though it is still in an early phase of adoption. Developed to emulate the energy and material flow management model in biological systems, its supporters position the CE as an alternative to the current take-make-waste extractive industrial model. CE aims to redefine growth, focusing on positive society-wide benefits. It entails gradually decoupling economic activity from the consumption of finite resources and designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital (Ellen MacArthur Foundation 2015).

The value of the CE stems from its explicit focus on the economy. Compared to sustainable development (which is widely seen as an environmental initiative, even though by definition, it is not), the dominance of economic thinking within CE concepts is clearly visible.

As hinted at earlier, according to Elia et al. (2017) and the European Environmental Agency (EEA 2016), the CE is characterised by its ability to reduce the input and use of natural resources; reduce emission levels; reduce valuable material losses; increase the share of renewable and recyclable resources; and increase the durability of products. It is based on three simple principles: design waste and pollution out of the system; keep materials and products in use as long as possible and as economically as possible; and regenerate natural systems.

Despite the CE's relative novelty, its unambiguous and application-oriented nature is a *positive* in fostering action toward sustainability at local, national and international levels. The CE is perhaps still a road less travelled. But, analogous to the German Autobahn, the CE is a smooth, straight, obstacle-free, high-speed freeway to sustainability. As exemplified in many domains in the European Union—the predominant promoter of the CE at present—the CE is not just another fancy term for waste management. The CE would help to reduce virgin resource extraction/input for economic processes, while also reducing the associated environmental impacts. As opposed to other economic models, the utility of the CE has been tangibly proven in applications in the EU. Accordingly, one recent estimation has suggested that CE practices such as chemical leasing, nutrient recovery in agriculture, materials substitution in the construction sector, and shared ownership models in transport systems could reduce up to 7.5 billion tonnes of CO_{2e} globally. This would bridge half of the existing emissions gap to reach the 1.5 °C target as outlined under the Paris Agreement (Schroeder et al. 2019).

Optimising material flows according to the principles of the CE is important for easing the pressure on land. In addition to this indirect positive effect on land use, the CE enables strategies for new land use systems based on the cascade approach and system thinking. For example, the "More Value from a Hectare" project, conceptualised and applied by the Institute for Applied Material Flow Management (IfaS) at Trier University of Applied Sciences for a new rural bio-economy strategy, is designed to enhance the resilience of agricultural systems, with a special focus on land and soil, while provisioning more services—or value—from each hectare of land utilized (Böhmer et al. 2019).

The CE would also create innovative business models. That means, besides generating profits, the CE would create employment opportunities—in other words, it contributes to social sustainability targets (see Schroeder et al. (2019) for some insights). Concerning economic aspects, according to the Ellen MacArthur Foundation (2015), a shift to a CE would reduce net expenditures on resources by €600 billion per year, improve resource productivity by 3%, and generate €1.8 trillion per year of net benefits in the EU by 2030.

In light of its origins and the compatibility of its transformative tools (i.e. MFM, ZE, etc.), the CE model's applicability seems universal. Clearly, the CE provides a very practical option to treat the societal metabolic disorder modern civilisation suffers from. Its versatility in solving developmental and environmental challenges simultaneously is also worth considering when promoting the CE as an effective tool in achieving the UN's SDGs.[4] Given the anticipated severity of impending resource and environmental crises (see Fig. 14.7 for some insights), the CE seems to be one of the best alternative paths to follow.

According to the OECD (2019), the material intensity of economies—in particular in OECD countries—is set to decline (by 2060); furthermore, growth in the recycling sector (i.e. use of secondary materials) will surpass that of the mining sector as recycling becomes more price competitive than mining. This is in part attributed to the strong presence and growth of the CE. However, citing a 2015 report by the European Academies' Advisory Council, Schroeder et al. (2019) have pointed out that transforming the current linear economic model to a CE model has been stymied by "a skills gap in the workforce and lack of CE programmes at all levels of education."

Nevertheless, the efforts of Europe's research and higher education institutions such as the Institute for Applied Material Flow Management (IfaS) of the Trier University of Applied Sciences[5] in Germany have been highly regarded locally and internationally by representatives of industry, academia and the public sector alike. For nearly two decades, IfaS has deployed its expertise on the CE on practical projects on five continents, offered graduate and postgraduate level education on the CE through dedicated degree programmes,[6] and continually disseminated applied knowledge regarding the CE through its signature events platform: the International Circular Economy Week and Conference.[7]

[4]See Schroeder et al. (2019) for some in-depth insights on this aspect.

[5]Find out more at https://www.umwelt-campus.de/ucb/index.php?id=home&L=1 and https://www.stoffstrom.org/en/.

[6]https://www.imat-master.com.

[7]https://icew.de.

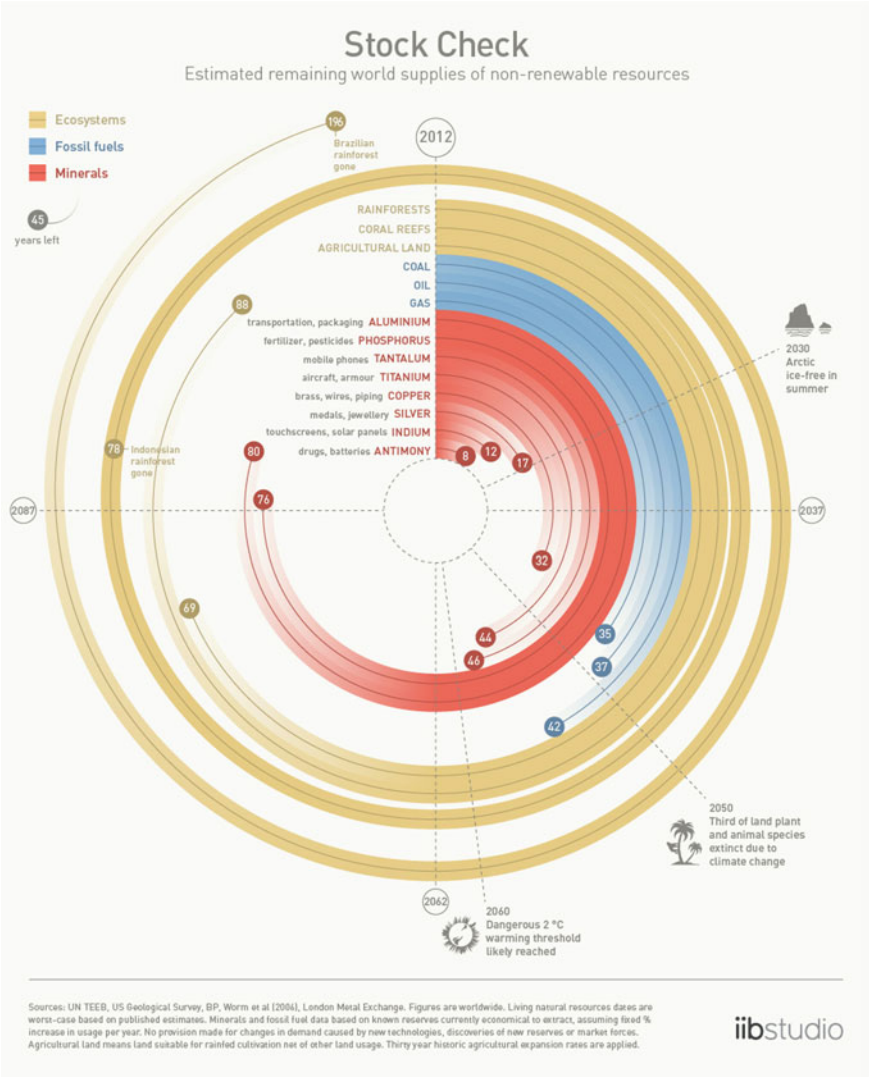

Fig. 14.7 Remaining non-renewable stock of resources (Source of image BBC Future: https://www.bbc.com/future/story/20120618-global-resources-stock-check)

The home base and foundation of this innovative education programme is the Environmental Campus Birkenfeld (ECB). ECB itself is a small-scale, decentralised and sustainable system of energy and material management; it has been purposefully designed as an object of study and a living laboratory for the specialised streams of scientific research pertaining to these areas. The following section explores the unique features of ECB in MFM.

14.2 Europe's First Zero Emission Campus: The Environmental Campus Birkenfeld (ECB)

This section gives an overview of the pertinent features and characteristics of the Environmental Campus in Birkenfeld (ECB) as a case study. Located in the Hunsrück Hochwald mountain region of the Rhineland-Palatinate, ECB itself represents a small-scale, decentralised system of material and energy management. ECB's energy and material management system also qualifies it as one of the largest of Germany's bio-energy villages (BEV), where at present nearly 2,600 people—including students, academics, researchers, administrative staff, private sector employees, etc.—enjoy CO_2-neutral electricity, heating and cooling. ECB can boast about its status as the first zero emission campus in Europe. Furthermore, it has been officially recognised as the Greenest University Campus in Germany since 2016. ECB is a unique higher education facility, where zero emissions system design is not only taught in theory, but is also implemented in practice by converting a former US reserve military hospital into an actual zero emission university campus. Hence, the zero-emission campus facility, with its innovative technology infrastructure, is not only home to students and environment-related study programmes, but is also an object of study itself. Especially in the context of land use, the repurposing of abandoned military brownfields into a centre of higher education and sustainability creates a perfect example of the CE.

The conversion process took place from 1994 to 1996 (Fig. 14.8b), following ecological construction principles and applying cutting-edge environmental technologies in the areas of sustainable repurposing of existing buildings as well as energy-efficient and material-efficient new construction. Energy aspects of the buildings such as heating, cooling and electricity supply have been entirely based on renewable energies. Moreover, the campus features biotopes and rainwater recycling infrastructure that contribute to the sustainable water management system of ECB.

In the vicinity of the campus, an eco-industrial park was also constructed to optimise regional material and energy flows connecting the campus via district heating and a low-voltage transmission grid. In 1997, a wood-chip power station was commissioned with an installed thermal capacity of 28 MW utilising about 65,000 tons of low-level and highly contaminated waste wood from forestry, agriculture, landscaping and industry annually; the power station can produce up to 8 MW of heat, 37.5 t/hour of steam and up to 8.3 MW of electricity for the environmental campus, neighbouring industrial facilities and the national electricity grid. In addition, the cogeneration units at the wood-chip power station utilise the biogas output of the nearby anaerobic digestion plant, which annually treats about 40,000 tons of municipal organic solid waste collected from the administrative districts of Birkenfeld and Bad Kreuznach. As a result, these local energy sources utilising regional biomass residues end up supplying a significant share of the campus' total energy demand. The remaining energy demand is covered by renewable energy installations on the campus itself. Various photovoltaic (PV) systems installed on rooftops and on the building

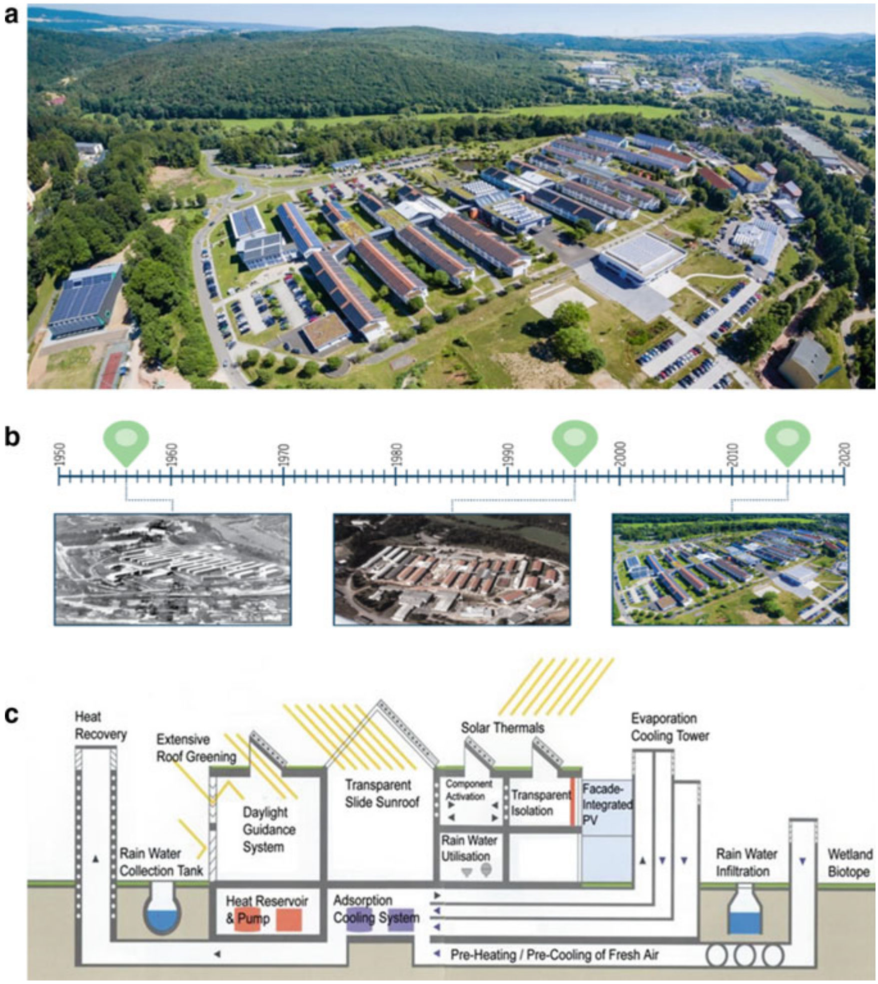

Fig. 14.8 **a** Bird's-eye view of ECB 2018. **b** bird's-eye views of ECB in 1950, 1996 and 2016; and **c** technical flow chart illustrating some of the energy innovations of ECB. Source: IfaS (2018) ECB and (2019). Green Campus Concept. https://www.umwelt-campus.de/en/campus/life-on-campus/green-campus-concept

façade, with an installed capacity of 510 kWp, cover another 40% of the total electricity demand. The performance of different PV module types and mounting systems are continuously monitored, displayed and employed as a subject for teaching and research. The use of solar energy is complemented by various solar thermal installations with a total capacity of 135 kW and a collector area of 270 m^2 that augment the heating system during the cold months. This solar thermal system also supports the solar adsorption cooling system, which has an installed cooling capacity of 175 kW. Thus, the total annual electricity demand of 1000 MWh and the total heating/cooling energy demand of 3700 MWh are completely supplied by renewable energies. With a new 99 kWp solar carport, a 100 kWh battery storage system, and five charging points for ten IfaS-owned electric cars, the campus is also progressively tackling the transport issue, which is still largely based on fossil energy (ECB 2019).

In the repurposed (and refurbished) buildings, a computer-controlled building automation system controls the natural lighting—maximised by daylight guidance systems and skylights—and the artificial lighting as well as the ventilation, heating and cooling of the buildings by employing motion detectors, luminosity sensors and CO_2 sensors. New buildings, such as the ones for student housing and the communications centre, have been built according to passive-house and/or energy-plus standards. The combination of the highest insulation and airtightness standards together with a roof-mounted PV system ensures that these buildings produce more energy than they consume. Heat exchangers for the recovery of waste heat in the used air coupled with geothermal preheating and cooling systems complete ECB's innovative HVAC system.[8]

The overall rational use of energy has been extended to other emerging areas such as street and building lighting. While various LED-based street illumination prototypes had already been in use and researched for many years, recently an entire street was retrofitted with state-of-the-art, highly efficient LED street lights, including a demonstration and performance control unit.

Aside from showcasing CE land use by converting an abandoned military complex into a high-tech university site, ECB also demonstrates aspects of the CE through sustainable landscape management strategies by developing biotopes based on separately collected rainwater. The ZE concept of ECB is extended to biotopes and biodiversity management, creating and maintaining protected areas and greened rooftops. Rainwater is collected on retention surfaces and redirected into natural water bodies or allowed to be channelled towards the aquifer. Part of the rainwater is collected, after mechanical purification, in two tanks and used for various greywater applications such as toilet flushing, irrigation and even as a coolant for an adsorption cooling system. The present system already avoids the discharge of rainwater into the sewer system. Nevertheless, modernisation of the wastewater infrastructure is currently underway, including water use minimisation strategies by installing vacuum toilets. The reduction of wastewater by separation of urine and brown water in one student dormitory is ongoing but not yet finished. In case of successful implementation, this system will be implemented to all dormitories on campus. With the complete installation of waterless urinals, the first step towards efficient water and nutrient management has already been taken.

[8] https://wissenszentrum-energie.ludwigsburg.de/,Lde/start/Bauen_Sanieren/gebaeudeenergiestandards.html, https://www.umwelt-campus.de/fileadmin/Umwelt-Campus/Oeffentlichkeit-sarbeit/Tech-Broschuere/2016_05_04_Broschuere-GrueneTechnologien-am-Campus_klein.pdf.

14.3 Sustainable (Bio)energy Villages and Communities

Following the example of ECB and partially motivated by its success, many communities in Germany have begun implementing similar strategies based on the idea of the CE and MFM. Communities all over the world face a multitude of critical socioeconomic and environmental issues in this energy-climate era due to their fossil-based primary energy use and their unsustainable land use patterns. Tackling these issues at the smallest political entity—the village—was envisioned and pioneered in Germany, where material and energy flow optimisation has taken the lead in creating self-sufficient and sustainable villages.[9] The bulk of the energy needs of these "sustainable villages" come from locally available, renewable energies like biomass, wind and solar power.

Due to the limited availability of biomass, more and more villages are relying on solar and wind resources for their energy supply (accordingly, the prefix *bio* is parenthesised in the terminology). As noted above, this original concept has since evolved to an advanced state where (bio) energy villages (BEV) tend to fulfil all their own energy needs, such as electricity, heating and cooling, and transportation from regionally available renewable energy (REN) sources such as wind, solar power, hydropower, and geothermal sources, as well as biomass; this makes them self-sufficient in terms of energy as well as independent from the national grids. Moreover, this initiative puts great emphasis on developing the land used for harnessing new sources of energy in a way that keeps resilience and biodiversity in mind.

Sustainable energy development is crucial to developing a BEV where regional added value, stemming from regional material flow management (rMFM), plays a pivotal role in achieving more general sustainability goals. The energy autonomy characteristic of BEVs is due not only to their high utilisation of regional renewable energy sources, but also to their high energy conversion and use efficiencies. In addition, features such as integrated water management, sustainable agriculture through sustainable soil management, and the use of bio-fertiliser and soil amendments—such as biochar—are integral parts of its design fabric. The (re)circulation of material and energy flows in a BEV unleashes enormous regional potential, referred to as regional added value (RAV), which would be otherwise unutilised or underutilised. Key elements of RAV include (but are not limited to) the reduction of greenhouse gas emissions (GHG); the creation of new products and services; the creation of employment opportunities; the reduction of the emigration of vital human resources; the reduction of environmental degradation and the loss of biodiversity; and the preservation of cultural heritage and indigenous knowledge by integrating them into the system.

In summary, BEVs based on zero emission strategies are much more than simply a new approach in environmental and climate protection. They provide the basis for

[9]There are about 150 established (bio)energy villages and another 43 under development in Germany under the FNR initiative. (See further details at https://bioenergiedorf.fnr.de/bioenergiedoerfer/liste/). Furthermore, the IfaS alone is currently in the process of developing another 94 new (bio)energy villages.

a sustainable economic policy based on the local potential that promotes innovation-driven modernisation of developed and emerging economies alike.

The utility of BEVs is well understood, but planning, developing and implementing BEVs is a complex process. Starting with the MFM process, a substantial amount of time and money is required to set up a BEV. Moreover, the required level of human capital, which can create opportunities out of problems, is large. However, the benefits of BEVs far outweigh the costs and complexities of implementation. Let us illustrate this point taking a common issue in any community or village: solid waste. Organic waste is a bothersome and expensive problem for communities in a conventional waste management context. However, in material flow management, organic waste is a vital resource and input for energy and fertiliser production.[10] Conventionally, this unused material flow is dealt with in compliance with environmental management and pollution prevention requirements. This siphons off scant financial and labour resources without generating any added value. As depicted in Fig. 14.3, *The Throughput System*, this would lead to a net loss of financial resources and further perpetuate an unsustainable system. As opposed to the aforementioned status quo system, should the principles of MFM and the CE be applied to this, the waste stream would no longer exist, and instead a resource stream for energy and fertiliser would be established. This, in turn, would create income, environmental benefits and employment opportunities as well. Such applications are the building blocks of BEVs.

This example can be transposed to most other socio-industrial metabolic systems as well, such as food, transportation, land use, etc., and can cover resource streams such as water, wastewater and energy. It is clear, therefore, that BEVs are sustainable villages with regard to energy consumption, energy provision, and the participation of local inhabitants in the energy management system. In the case of biomass use for energy production, land use must be decoupled from the pressure on biodiversity, soil erosion and nutrient oversupply. In this energy-climate era, it is necessary to consider carbon and water storage in appropriate respective sinks/reservoirs to avoid undesirable externalities. This is already happening in Germany.

An important question worth asking at this point is if it is possible to achieve sustainable, decentralised community development. As mentioned earlier, it is a good idea to perform a thorough systems analysis (usually an MFA) at the outset to determine the required level of human and financial capital. This helps clarify the reasons for the poor allocation of resources—energy, water, money, human capital, etc.—and as a consequence helps to prepare, design and execute technical and administrative solutions. As experienced in many of IfaS' applied projects, the resources needed to organise this change or shift can be retrieved within the system itself. Otherwise, market or public/government programmes may provide the necessary resources. The

[10] For example, 1 ton of organic material is equivalent to 100 m^3 of biogas with at least 50% CH_4 content, which means approximately 50 L of oil. The fermented residues contain in addition approximately 600 kgs of organic fertiliser.

latter, of course, is the most convenient, yet not always the most efficient, way to approach the critical issue of transaction costs.[11]

The following section presents two case studies on particular aspects of sustainable resource management: transferring know-how and knowledge on sustainable development to German communities. These government-funded projects, carried out by IfaS, follow two tracks. First, *The Sustainability Roadshow* is a communication programme specifically developed to disseminate research findings and communicate knowledge and know-how on decentralised sustainable development. Second, the *Dorfkern Limited* project is an example of a market mechanism to support sustainable resource management (SRM) and sustainable development (SD), demonstrating a public–private partnership (PPP) approach to securing necessary funds and allocating the necessary human capital to the sustainable development of small villages.

14.4 Programmes and Concepts

14.4.1 The Sustainability Roadshow

Since 1999, the German Ministry of Research and Education (BMBF) has offered research grants for sustainability research under the *Forschung für Nachhaltigkeit* (FONA) programme. After spending billions of euros and commissioning over a hundred projects,[12] questions were raised on the impact of the projects in the real world.

IfaS was contracted in 2018 to design and implement a research project on the transferability of FONA products to communities in Germany. The project was divided into four areas of activity:

1. The analysis and evaluation of FONA products with regard to their transferability;
2. The selection of feasible products for practical transfer;
3. The presentation of these products to German communities in six major Roadshow conferences;
4. The selection of 27 model communities from among Roadshow participants.

The analysis of the research projects from the FONA database immediately showed the difficulty of maintaining sustainability and transferring the concept to communities. Only a few products were left for transfer and even fewer were developed for practical application. The definition of sustainability and sustainable projects needed to be clarified, as some projects and outcomes were of questionable value according to the 17 SDG indicators. Using new software tools to optimise and accelerate the search for available commercial real estate in communities might help the local economy, but otherwise interfere with other aspects of sustainable land use.

[11] Based on our own experiences.

[12] €3.3 billion during the period from 2005 to 2014, with another €2 billion from 2015 to 2020.

The selection of feasible products was done in close cooperation with the participants of the projects, specifically researchers, academics/professors, consultants, and the ministry itself. Out of 87 projects, 62 were selected in the first phase. In the second phase, interviews with project directors and researchers led to a final 26 projects with a total of 32 specific products.[13]

We classified the projects into four categories: water/wastewater, energy, land use, and general issues. The "general issues" category was designed to introduce sustainability, zero emissions approaches and material flow management to the audience, and to offer a glimpse into the future, such as by introducing examples of best practices.

We then assembled these into presentations. One of these general presentations described successful project examples, model communities, added value assessments, and policy support. Another one dealt with specific financing options.

The presentation to German communities was designed to cover most of Germany. Six different cities—Nuremberg, Hannover, Stuttgart, Leipzig, Schwerin and Emsdetten—each hosted a one-day or two-day conference. The conference venues were selected to allow as many mayors and public experts as possible to attend.

372 participants participated in four meetings; 178 were representatives from small villages and towns. The conferences were organised as one-day and two-day events. Two-day conferences offered attendees the opportunity to meet in the evening, reflect on the day's information, and start networking for implementation. This was crucial, because the projects energised and intellectually challenged the audience. Accordingly, there were many requests for more information, especially for implementation support. Out of these 178 participating communities, 27[14] model villages and towns were selected for intensive transfer of know-how and coaching within the year.

The next steps of the process will involve a detailed data analysis of each community, followed by stakeholder interviews. This research will then be used to formulate ideas for the transfer of existing concepts or products, and transfer them to communities. At the end of the process, which will involve town hall meetings to facilitate ownership among local residents as well, the respective town councils will decide on implementing a proposed product or strategy.

14.4.2 "Dorfkern" Companies

A "*Dorfkern*" company is a new strategy developed by IfaS to cope with the high transaction costs and complex efforts to achieve a sustainable village, a resilient village or a (bio) energy village (Heck and Blim 2019).

[13] Some projects had multiple products or solutions that could be transferred.

[14] One additional model village was selected due to the amount of excellent applications.

In this approach, several small villages set up a not-for-profit company, which mobilises the resources to do a proper MFA, and develop detailed projects in the fields of energy, water, land use and infrastructure. The non-profit company then uses the MFA as a guidebook to develop projects and prepare the implementation legally and economically. In addition, the *Dorfkern* is designed to support the aspects of technology expertise and financing. *Dorfkern* is mainly owned by the consortium of villages; however, there are provisions for inviting other shareholders.

Dorfkern is a clear solution to addressing the issues that a small village or a community cannot address alone. Individual villages or communities have options, but alone they are too small to recognise issues and implement solutions. *Dorfkern* further rectifies the problems of the lack of human capacity, know-how, and legal and financial resources as a large, collective entity, effectively.

A *Dorfkern* company's success comes from the capitalisation of unused or non-monetised potential in villages and communities. These opportunities include the installation of solar panels on roofs and other free space, LED street lighting, the installation of heat pumps, increased building insulation, implementation of district heating, increased capacity for electric transport, the changing of land use with new marketing ideas such as solidarity farming, harvesting biochar from farm hedges, etc. The MFA helps stakeholders find opportunities and turn them into assets, which they can subsequently offer on the market. As the first stakeholder discussions have shown, potential investors have been interested in buying into these opportunities and making a good return on investment.[15]

14.5 Conclusions

Small-scale systems are direct victims of the worldwide plundering of energy and resources, and also have been severely affected by the throughput system of economy. Accordingly, resources and sinks have been overused, and neither efficiency nor effectiveness has been given sufficient attention. As a result, small-scale systems have lost opportunities and competitiveness, and in turn, have become a burden. In this energy-climate era, these issues are becoming even more severe, impacting all aspects of sustainability. In rural areas—where these small-scale systems are dominant—changes in precipitation regimes, frequent drought, increased soil erosion and biodiversity loss have pushed stakeholders to their limits. Furthermore, and characteristically for small-scale systems, the know-how, money and management skills to organise *change* are scarce.

A shift from a throughput society toward a more sustainable metabolic system such as the CE would pose major challenges not only for small-scale systems but for all systems. However, using an MFM methodology would help turn these challenges into targeted opportunities for the decentralised management of resources and sustainable development. As this chapter has pointed out, small-scale systems such as small

[15]Project talks with Naturwind, Energie Leipzig about financing Dorfkern GmbH, 2019.

villages and communities have multiple opportunities similar to those of large-scale systems. However, strategic planning and management solutions are necessary at the level of project deployment and resource mobilisation, as exemplified in the case of ECB and *Dorfkern* companies.

In light of that challenge, we presented two randomly chosen management approaches to turning small-scale systems into resilient, sustainable systems—i.e. BEVs or communities. The Sustainability Roadshow has transferred thus far unused or little-used research results to small communities and towns. Best-practice and next-practice solutions developed using BMBF research grants have been interwoven with the challenges and problems of small systems. Regional conferences and the selection of model communities push research directly into the heart of small systems. Stakeholders become motivated and informed, and receive implementation coaching. This is an ongoing project, which so far has demonstrated very positive results.

A second, more market-driven example, the *Dorfkern* company, demonstrates how to change small-scale systems based on a throughput society into sustainable systems by employing a business approach. Achieving SRM and the SDGs via a market-based small-scale system by bundling resources and capabilities is an innovative approach that could be deployed in almost any (rural) geographic location in the world.

In summary, there is no lack of potential and solutions, but rather a general lack of management and strategy, as well as courage. Referring to courage, a quotation from Nelson Mandela seems appropriate to end this work: “It always seems impossible until it’s done!”.

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