

Article

Sustainable Urban Regeneration Based on Energy Balance

Arjan van Timmeren ^{1,*}, Jonna Zwetsloot ², Han Brezet ² and Sacha Silvester ²

¹ TU Delft, Faculty of Architecture, Julianalaan 134, 2628 BL Delft, The Netherlands

² TU Delft, Faculty of Industrial Design, Landbergstraat 15, 2628 CE Delft, The Netherlands;
E-Mails: jonnazwetsloot@gmail.com (J.Z.); j.c.brezet@tudelft.nl (H.B.);
s.silvester@tudelft.nl (S.S.)

* Author to whom correspondence should be addressed; E-Mail: a.vantimmeren@tudelft.nl;
Tel.: +31-15-27-84991; Fax: +31-15-27-84178.

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Abstract: In this paper, results are reported of a technology assessment of the use and integration of decentralized energy systems and storage devices in an urban renewal area. First the general context of a different approach based on 'rethinking' and the incorporation of ongoing integration of coming economical and environmental interests on infrastructure, in relation to the sustainable urban development and regeneration from the perspective of the tripod people, technology and design is elaborated. However, this is at different scales, starting mainly from the perspective of the urban dynamics. This approach includes a renewed look at the 'urban metabolism' and the role of environmental technology, urban ecology and environment behavior focus. Second, the potential benefits of strategic and balanced introduction and use of decentralized devices and electric vehicles (EVs), and attached generation based on renewables are investigated in more detail in the case study of the 'Merwe-Vierhaven' area (MW4) in the Rotterdam city port in the Netherlands. In order to optimize the energy balance of this urban renewal area, it is found to be impossible to do this by tuning the energy consumption. It is more effective to change the energy mix and related infrastructures. However, the problem in existing urban areas is that often these areas are restricted to a few energy sources due to lack of available space for integration. Besides this, energy consumption in most cases is relatively concentrated in (existing) urban areas. This limits the potential of sustainable urban regeneration based on decentralized systems, because there is no balanced choice regarding the energy mix based on renewables and system optimization. Possible solutions to obtain a balanced energy profile can come from either the choice to not provide all energy locally, or by

adding different types of storage devices to the systems. The use of energy balance based on renewables as a guiding principle, as elaborated in the MW4 case study, is a new approach in the field. It may enhance existing communities, and in some cases result in both the saving and demolition of parts of neighborhoods, which were not foreseen, while at the same time direct introduction of flexible appliances within the energy system for (temporary) storage. It is concluded that the best achievable energy balance in the MW4 area consists of an elaboration in which a smart grid is able to shift the load of flexible devices and charge EVs via smart charging while energy generation is based upon the renewables biomass, wind, tides and the sun. The introduction of new sustainable technologies makes a protected environment for development evident. As for system configuration, the choices arise mainly from technical and social optimisation. In fact, the social, or user-related criteria will be decisive for enduring sustainability.

Keywords: energy approach planning; sustainable energy balance; storage; flexible devices; infrastructures; case study

1. Introduction

In this paper we present the main results of an integrated scenario development study for the introduction of electric vehicles (EVs) and other flexible devices at the ‘Merwe-Vierhaven area’ at Rotterdam. The scenario development study is part of a larger research project that has been executed by researchers of three different faculties of the Delft University of Technology within the ‘Pieken in the Delta’ framework, attached to the sustainable urban (re)development of the greater Rotterdam Delta area. This specific research project, called ‘DIEMIGO 2.0’, is a sequence of a previous DIEMIGO research, part of TRANSUMO; a national Dutch research program that aims to initiate and support a transition to a sustainable mobility system that supports an international competitive position of the Dutch economy (‘profit’), that respects the environment (‘planet’), and that offers high quality accessibility and mobility for people and the goods they need (‘people’). This ‘DIEMIGO’ research project had two main objectives: to develop a preliminary methodology to select and design effective solutions for the implementation of large scale electric mobility and electric charging infrastructures into the built environment; and to develop and design a scenario specifically for urban area development (including electric mobility solutions, charging interfaces, power grid, urban design implications, and strategic location choice). This paper considers especially the results of a sub-research study and scenario development for the elaboration of the Merwe-Vierhaven area. First, the general context of a different approach on infrastructure in relation to the sustainable urban development and regeneration from the perspective of the Triad people, technology and design is elaborated. At different scales, however, starting mainly from the wide perspective of the urban dynamics. It includes a renewed look at the ‘urban metabolism’ and the role of environmental technology, urban ecology and environment behavior focus. Second, the potential benefits of strategic and balanced introduction and use of decentralized devices and electric vehicles (EVs), and attached energy generation based on renewables

are investigated more in detail in the main case study of the ‘Merwe-Vierhaven’ area (MW4) in the Rotterdam city port in the Netherlands.

2. Towards a Circular Approach of Resources and Wastes in Urban Planning and Retrofit

The road to permanent urban development appears to be hard to find. In modern town planning in existing urban areas we need new inventions and the introduction of intelligent light-infrastructure. Only closed cycles for processes and use of material and smart generation and cascading of renewable energy could, in the long run, make the urban environment permanent. Therefore, it is necessary to look beyond boundaries: not only physical boundaries (between areas or countries), but especially boundaries of the various scale levels of solutions, the interrelated networks (energy, water, waste/nutrients), the public space and, particularly, their mutuality. It induces an exploration of the ‘urban metabolism’ with underlying social needs and the finding of solutions that allow the urban areas and infrastructure to fit the changing objectives, especially sustainability.

Within this context cycles are the key condition for both sustainability and stability in nature to come into existence. For example, life is characterized by a cycle of matter in combination with a flow of energy coming in as sunlight and disappearing as radiation, among other aspects. In a closed system, matter cannot go beyond its boundaries. In principle, energy can go beyond a system’s boundaries. A sustainable built environment will not be completely reached until the flows of materials can be closed and the cycle can be managed without too many manoeuvres and losses of energy and other materials.

Within the research tradition of environmental technology, attention to water and energy saving has always been obvious, because of reduction in demand, enhancement of efficiency and renewable sources since the second energy crisis (in 1973). There is a strong segregation between the various participants, as there is between the various disciplines concerning solutions for matters including generation of renewable energy (wind *versus* sun), ‘sustainable water management’ and the development of the necessary water concepts and waste/material management. In the first few years after the energy crisis, the energy policy was also strongly characterized by institutional fragmentation. Until now, most research projects on environment related flows of energy, water, waste, nutrients and materials do not make any attempt to rise above the compartmentalized policy domains. Many well-meant initiatives stick in thematic and effect-oriented solutions without reaching a certain degree of integration or added value of environmental measures. The corresponding infrastructure is often restricted to transport infrastructure with its own status, dominant parties involved and path-dependent policy. At the same time, few people in society deny the necessity of sustainable development: to preserve or enhance the environment or our living surroundings, to distribute wealth and welfare, and to offer all people scope to develop themselves and more awareness. However, the emphasis on the restriction of the environmental load will soon lead to resistance. Public support is lacking at times when this has consequences that cannot immediately be capitalized within the current economic models. Besides this, social aspects are important, as “Most people like progress, fewer like changes” [1]. In sustainable urban planning and regeneration, the lack of integration of solutions that help to realize (or improve) sustainability of the so-called essential (or: critical) streams (water, energy, waste/wastewater) also obstructs potential alternatives. Therefore, the emphasis should be on guiding a transformation process, and perhaps on expanding environmental space. Critical to the implementation

of this option of expanding the environmental space, or better: of integrated resource management in the urban living environment from the perspective of an urban metabolism [2], is knowledge dissemination of low exergy solutions including strong feedback systems—constructive feedback loops [3]—between the different physical scales (site, neighbourhood, city-region, *etc.*).

Composite measures of sustainability provide useful insights to the environmental impacts associated with human activities, but, in themselves, are not the solutions for abandoning traditional paradigms. Sustainable spatial planning and development must be able to guide the spatial consequences of changes. Thesis of the sub research presented is that it is more appropriate to realize the pursued replacement of existing end-of-pipe technologies with an integrated approach and healthy, sustainable solutions at the intermediate scale of an urban district. Especially in the case study this paper tries to demonstrate that in case of existing urban areas such an approach will be necessary to avoid paradigms, and that there is the need to include interdisciplinary approaches to the integration of strategies for raising public awareness, marketing of the different qualities of energy (exergy), and establishing more decentralized installations. Within this framework, integration strategies for waste management and sanitation, together with energy-generation comprise direct linking with neighboring subjects like electrical vehicles (EV) based mobility (and other flexible devices), agriculture, aqua and horticulture, health care and food security. The basis of this research forms an urban planning that is based on ‘interconnection’, critical streams management in general and the organization, maintenance and assurance of indispensable parts of closed cycles.

3. Actual and Emerging Strategies for Improving Sustainability in Urban Development

Sustainable development is a moving target: knowledge, technologies, and skills are being developed every day. At the moment few integrated theories for achieving sustainability in the built environment can be identified. In fact sustainability often relies in the management of transitions—a shift to doing things differently—that tends to be specific to each site, rather than a constant recipe or ‘one size fits all’ type solution. The issue of sustainability is even more complex in the case of redevelopment or regeneration of existing urban areas. Redevelopment can be defined as “one or more public actions that are undertaken to stimulate activity when the private market is not providing sufficient capital and economic activity to achieve the desired level of improvement” (American Planning Association [4]). This public action often involves measures such as direct public investment, capital improvements, enhanced public services, promotion, tax benefits and other stimuli including planning initiatives such as rezoning. This is slightly different with regeneration, defined as “a holistic process which aims to reverse the economic, social and physical decline of places where market forces alone will not suffice. The planning process provides the opportunity to enhance the role and capacity of communities as well as balancing community, business, environmental and individual needs. Effective regeneration requires active and meaningful long-term community engagement and involvement, as well as changes to the physical environment” (Royal Town Planning Institute [4]). So, whereas redevelopment focuses on monetary investment and physical changes, regeneration focuses on the existing community and possible social decline. This difference is also related to a slightly different look (based on the difference here in definition from respectively American and UK planning associations) with respect to gentrification. While in America gentrification might be seen as

inevitable and therefore an accepted side effect of redevelopment, in Europe it is seen as sometimes inevitable and therefore a tragic side effect of regeneration [4].

With respect to the introduction of sustainability as a key-force for regeneration, one way of addressing the complexity of the task at hand, often used, is through certification standards. Certification programs can cover most of the aspects of urban property development, including setting targets for site decontamination, use of recycled materials, Brownfield redevelopment, provision of public transport, options to discourage fossil transport use, energy consumption and efficiency in buildings, water recycling and waste management. As for policies, best-known directives at the moment concern CO₂ and are energy performance directives. An example of the latter in the Netherlands is the EPC (Energy Performance Coefficient) directive.

Besides certification standards sustainability approaches are often based on corporate responsibility theories. Some examples here are the ‘Triple Bottom Line’ approach [5], the ‘Creating Shared Value’ strategy [6], and ‘The Natural Step’ [7].

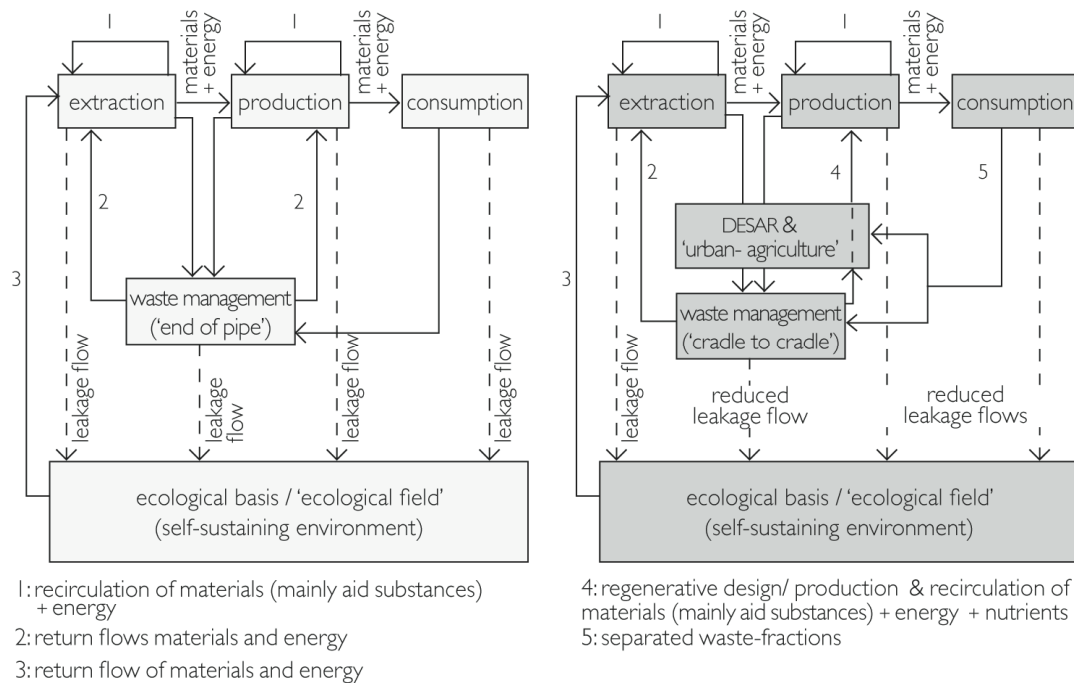
In recent years, (local) governments have embarked on a passionate race to achieve climate goals before their neighbor. A relevant example here is the Rotterdam municipality in the Netherlands, the context of the main reference study explained in this paper in Section 6. Largely due to incentives in public funding, cities have appropriated sustainability at large as a standard for competitiveness and means to attract various types of investment. Some international examples include ‘the Rotterdam Climate Initiative’, ‘the 10 Melbourne Principles’, ‘the Vancouver Climate Leadership’ and ‘the Chicago Climate Action Plan’ [8]. At building and project development level the application of building certification programs is coming more and more to the forefront. Their purpose is to encourage measures in all possible areas of sustainable (re)development or even regeneration beyond actual design and construction, from the sourcing of materials to the management of a building (or area) once completed.

4. Towards an Urban Metabolism and a Need for Decentralization

It is important to realize that environmental effects are not necessarily looked on as negative. They may have positive aspects as well, and these may compensate the negative effects to a certain extent. The well-known ‘Eco-device Model’ has incoming and outgoing flows, which are linked to primarily harmful aspects for the environment (incoming and outgoing flows) and secondarily harmful aspects (connected to the system or area under investigation). The disadvantage of a model such as the Eco-device Model is its constrain on the stochastic behavior of input and output. It is important to see the ecological device in a larger framework, as part of the so-called Environmental Circuit. In this ‘E-circuit’ the in/out chain is specified for the three main units: extraction, production and consumption, which have a continuous relation with the ecological basis through so-called leakage flows (Figure 1). An important link in the desired transformation of our society from one based on linear attitudes to resources and wastes towards a circular one, is a different way of handling sustainable energy and (ecological) sanitation (including waste management). In the schematic representation of the Environmental Circuit, Decentralised Sanitation, Energy and Reuse (DESAER) can be placed between the (end-of-pipe) waste disposal and the three main units (see Figure 1).

This implies a (better) formalization of the existing ‘leakage flows’ between the cultural world and the natural world, or ‘ecological field’ as a self-sustaining environment [9].

Figure 1. ‘Environmental Circuit’ and the introduction of DESAER to reduce and reuse ‘leakage flows’.



The metaphor of a city, or living environment, as a living organism with a collective urban metabolism can be traced back for more than 150 years. More recently, the concept of urban metabolism has been used as an analytical tool to understand energetic and material exchanges ‘between cities and the rest of the world’ [10]. It can also be seen in close cooperation with Industrial Ecology [11]. In cities, the concept of metabolism was expanded by Tansley (1935) [12] from living cells to encompass material and energetic flows for inorganic construction of settlements [13]. This so-called ‘Urban metabolism’ is a framework for modeling complex urban systems’ material and energy flows as if the city were an ecosystem. The positive side of this approach is that the dynamics of cities can be studied (on more than ‘traditional’ mobility and relations built/(un)cultivated alone) in relation to scarcity, carrying capacity, and conservation of mass and energy [14]. However, there is also a counter side to this approach: urban metabolism in a way is opposed to traditional urban planning, in which social, cultural, political and technical dimensions dominate over the biophysical dimension: hence, it synthesized environmental and biological science into the urban planning discipline. More recently, many interpretations followed concerning the industrial ecology and urban metabolism approach. Important to mention here is “The changing metabolism of cities” [15], which updated the definition of urban metabolism to ‘the sum total of the technical and socio-economical processes that occur in cities, resulting in growth, production of energy, and elimination of waste’. It introduces the essential component of integration of both technical as well as social perspective.

Within the context of urban redevelopment and the perspective of urban metabolism, scale related decisions, like the covering of distances and seize of (ground related) space are increasing in importance every day. Especially with respect to energy, the problem in existing urban areas is that

often these areas are restricted to few energy sources due to the lack of available space for integration. Besides this, energy consumption in most cases is relatively concentrated in existing urban areas. Apart from the lack of space the increased importance to look critically to the scale of solutions is also a result of the ever inclining load of the existing, mostly aged (technical) infrastructure and also the lack of space for replacing technical infrastructure due to amortization of existing technical infrastructure that stays in the grounds as residue. Another consequence of the existing solutions, mostly based on the need to transport energy, water and waste to centralized plants outside cities and consequently an enormous amount of technical infrastructure is the related use of energy, water and materials. This technical infrastructure has a non-negligible environmental impact and is a relatively expensive feature in urban planning. Apart from the (uncontrolled) leakages, inclining rotational speeds, changing technologies and especially aging of existing technical infrastructure (in Europe in particular) might lead to huge problems and costs within the next decades [16].

More actual is the rising call for a needed improvement of the flexibility of the existing built environment: buildings or parts of buildings and even whole districts or urbanizations. Precisely this call for flexibility can be connected to (a) clear optimum of scale(s). The more centralized solutions of today seem to translate this ‘flexibility-concept’ towards the creation of overcapacities of technical infrastructure and treatment- and generation systems. Science, and more often also the market, brings up solutions that imply smaller scales of implementation [9]. The consideration in these cases is a possible reduction of infrastructure and a better tuning in to the demand and therefore more flexibility. Apart from that, these kinds of smaller systems and more variable climate or nature-based technologies can be introduced relatively simply and therefore can also be used to create extra (real sustainable) capacities. There are also several disadvantages. Natural technologies and small-scale generation based on renewables (with increased variability of each of these sources), for example, are more vulnerable in case of inaccurate use or sabotage and are less effective in so-called peak shaving. Also, in general, they depend more on natural light and/or open space and among other things this means that these renewable sources have a relatively low energy density and subsequently large use of ground. Decentralized systems turn out to be able to gain efficiency advantages as compared to fully centralized systems, particularly through the design of an integrated system of energy generation and supply, and e.g. through the connection of waste water treatment systems to energy recovery and nutrients recycling. Besides this, they more often offer better solutions in places where traditional sewers or energy infrastructures have to be upgraded or are not possible, because of existing buildings, infrastructures and soil conditions, available budget, water conditions or related rules and regulations. In case of energy systems, they offer opportunities for introduction of smart grids, which within a larger network geometry can better handle the need for variabilization of costs, semi-public or private management, and how to handle the “first mover” problem in spatial development.

5. The Role of Existing Infrastructures

Unlike the more traditional infrastructure restricted definitions, this research includes especially the post-industrial and ‘invisible’ infrastructure. Infrastructure concerns in this vision not only the (physical) infrastructure, but “all goods and services that social activities facilitate as far as these bring along direct or indirect spatial effects” [17].

To be able to change the existing built environment in accordance with the principles of sustainable development there is a need to turn around the inter-relationship between the infrastructures and the societal needs. To do so, one ought to pose the question: what is the real need for this specific infrastructure and which is the best physical form of appearance? Additionally one should think about the relation between (technical) infrastructure and the social goals that are aimed at and one should do this as much as possible independently from the existing ways of thinking and existing arrangements. One has to (newly) reflect upon which social needs exist and which (technical) infrastructure belongs to these needs. Within this approach one should also try to integrate the different sorts of infrastructures and the different aspects of sustainability in this reflection.

Decisive aspects in the existing built environment, within the continuing urbanizing, and connected world with crucial dependency on integrated networks, will be the cognitive flexibility of the concept of generation, treatment and transport of the critical flows; the adaptability to alternative technologies; the size of space; and the overall independence and resiliency to change, failure, inaccurate use and sabotage. Differentiation and urban flexibility (for buildings and infrastructures) are pre-conditions for anticipating long-term uncertainties, due to actual liberalisation processes and rising complexities.

Sustainable starting-points are suppressed more and more by these changes. However, at the same time especially the urban scale can start up the necessary process of transformation towards real sustainable development, for it takes the best of two worlds. At present, however, technical infrastructures still are too directive to urban development, especially in existing urban areas; however, often even dictating societal needs. It is important to change the general attitude towards the different components of design, development, use and management of urban areas. A way to do this is the 'interconnection' of different cycles and included devices, and solutions within neighbourhoods, districts and cities addressing to their hinterland from the point of view of an 'urban metabolism'.

Adapted, or newly planned and constructed infrastructure within existing urban areas is largely being determined by the 'suprastructure' ("the different standards of (societal) needs and goals which form the basis of all physical networks of these logistical chains, including the (technical) infrastructure" [18]), which results from the existing balance of power or customs of certain institutions [19]. One could state that the infrastructure of the essential (or critical) streams, due to this 'path-dependent', long term character and the existence of a limited number of dominant actors per network or stream, is determinative to what degree a project—varying in scale from a (part of a) building to a city—will or can be sustainable. In case of the energy streams, for instance, conventional sources of energy are being extracted, isolated and in high concentrations brought together in central installations in which they are converted into large amounts of energy which via large distribution networks can supply large areas with energy. The loss during conversion and distribution is overshadowed by the abundance of energy that can be generated inside these centralized power plants. Most of the sustainable energy sources, however, are present (almost) everywhere but in relatively small concentrations, and most of the times also less continuously available.

An important factor is that there is a matter of a small but strong network with one or two dominant 'actors' for each of the different circuits or 'streams'. In the end, these separated circuits are hindering the necessary threshold to a sustainable society. New sustainable technologies are continually being developed in all sectors, but the assimilation by society often falters. There is a matter of the so-called 'Collingridge dilemma': if a technology is still young, the social implications are barely known and if

the social implications are known, the technology is indebted in such a way that it is impossible to adapt it to the desires of the different actors [20].

Three knowledge-systems play a part: a system of natural scientific explanations, a system of societal explanations and a system of individual value judgments. They can be encapsulated as ‘technology’, ‘culture’ (behavior, needs) and ‘structure’ (institutions, economics, *etc.*).

Lately, in several scientific publications and policy planning documents, more attention has been paid to the malfunctioning of the different urban policies of today and the additional spatial investments at superior (regional) scale. The Dutch Scientific Board for Governmental Policies (WRR) states, “the system only facilitates standard solutions” [21]. Apart from that, actual policies tend to lead to long procedures and delays that due to its relative slow launching, also face difficulties to follow the needs of society. In the Netherlands, actual policies put more emphasis on so-called ‘urban networks’ instead of cities or conglomerates. However, in practice the mutual administrative- and policy adaptation on this scale appears to be inflexible and rarely leading to fathomed planning, not to mention social participation. Both a more local (independent systems) and a more regional oriented planning (interconnection) in this case could be the answer. However, with respect to execution of more differentiated and decentralized planning processes, most of the times these are stuck to the existing ‘body’ of physical infrastructure and accompanying administrative, often not very flexible institutions and standards. This also reduces further possibilities of participation. If one wants to come to urban planning that gears to the ever faster changing society this barrier also has to be broken.

With respect to this important issue of participation, especially in existing urban areas the necessary improvement of “reflexibility” (which I define as “the use of the users’ critical intelligence and commitment in an environmental-technical, aesthetic and political or socio-political way for the design of environmental-technical and spatial processes”) can be achieved through the participation of users in the redesign, the construction and even the management of the built environment or parts of it. Experimentation, learning knowledge generation, creativity and responsibility are common characteristics of all lifestyles [22,23]. Community wellbeing is linked to participation in the process of development and in community activities.

Finally, there is the fundamentally different nature of environmental- and economical interests. The environment related problems are mostly rather vague. The problems are being derivated to a larger area or are being shifted to the future, and thus only incremental improvements are realized. Economical interests are mostly more concentrated. In addition, one-sided representations of interests can slow up sustainable renewal. This process is improving in some sectors, due to the started privatization and therefore the need for ‘redesign’, to cope with the additional competition. Redesign in this case, however, is the re-examination of interests and plans towards a more sustainable direction. The actually needed phase of ‘rethinking’, the taking care of ongoing integration of coming economical and environmental interests, is still a long way away from these, mostly conventional parties. This still appears to be the assignment for governments and science.

6. Urban Renewal: The Rotterdam City Port MW4 Case Study

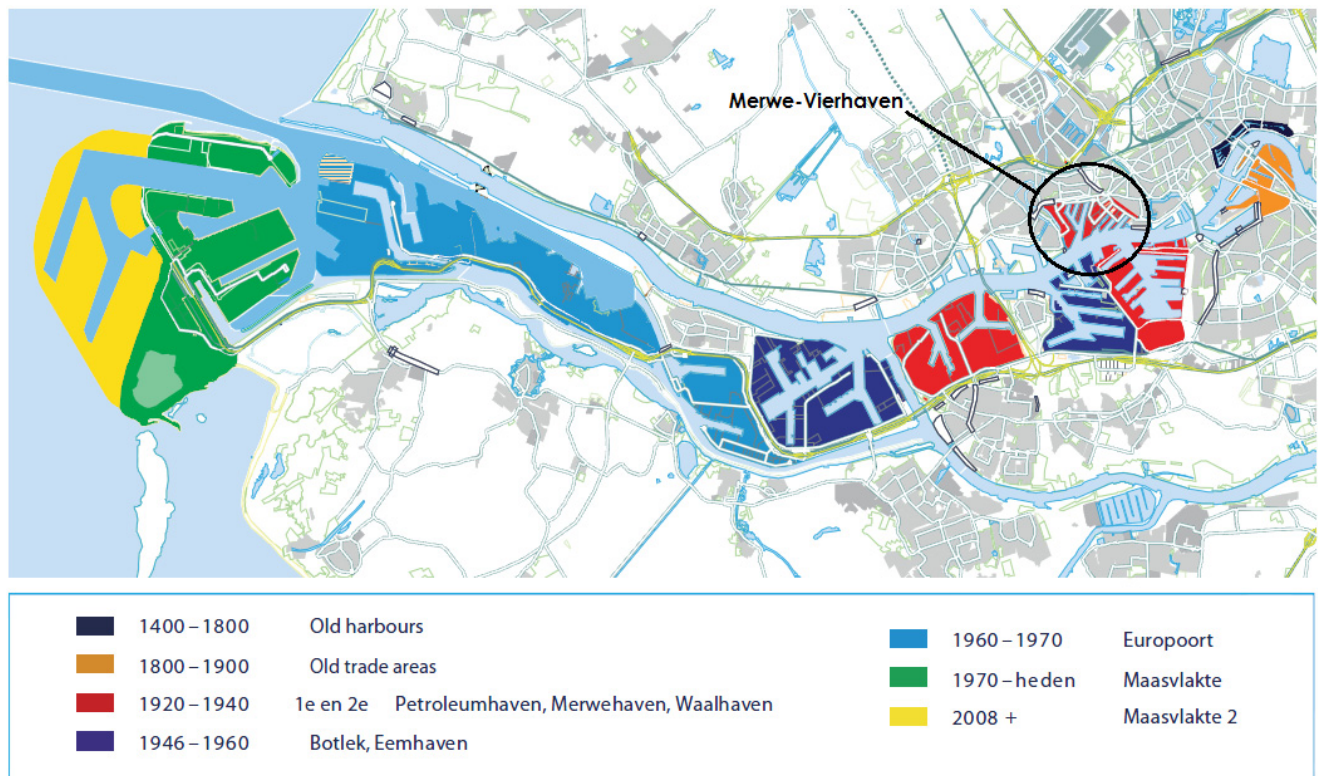
As discussed in Section 4, science, and increasingly the market too, bring up a rising number of solutions that imply possible smaller scales of implementation. The considered benefits are a possible reduction of infrastructure and better visibility and tuning in to the demand and therefore more flexibility. Decentralized renewable energy systems can fulfill local energy demands while decreasing the pressure that energy consumption puts on the environment. As concluded in Section 3, the largest challenge in implementing these systems is found in urban environments where the energy consumption is very concentrated. This challenge is addressed in the presented research sub project, and case study of the ‘Merwe-Vierhaven’ (MW4) area in the Rotterdam city port. At the moment the MW4 area is used for transshipment of fruit and juices but in 2025 it should be transformed into an attractive and sustainable area for living, working and leisure activities [24]. The presented outcomes concern a study on the energy balance of the M4H as performed by Zwetsloot [25]. As explained in the introduction, the conclusions are considered within the conclusions of the larger TU Delft research project DIEMIGO 2 that will be finished in the beginning of 2013. This research project is focusing on potential benefits of strategic and balanced introduction and use of new product/service based concepts, like the introduction of shared (smart grid connected) electric vehicles (EVs) and other devices, and attached generation based on renewables. The background is that around the world several concepts for EV charging and EV/building interfaces have been developed, or are under development. In general, however, integrated smart grid concepts, comfortable charging or user focused services and innovative charging are still lacking and are mostly based on the principle of relatively simple “technical fixes” and do not address problems to be solved in case of large scale introduction of Electric Mobility [26].

Rotterdam is the largest seaport as well as one of the main industrial hubs of Europe. At present the port has a total surface area of about 10,500 ha, stretched out over 40 kilometers, to profit optimally from its connections with both sea and hinterland. While the city of Rotterdam flourishes from the economic benefits the port gives, the growth of the city has resulted in a so-called “city port”: the old port is being surrounded by neighborhoods used for living, working and leisure.

While Rotterdam is searching for space to expand its boundaries as a city to host the increasing population, the city port seems to offer a lot of opportunities, with its nice location on the river banks and its adjacent former docklands. For this reason, the “Oude haven” (Old port) and the “kop van Zuid” (Southbank) have already gone through a process of regeneration, in which an urban environment replaced industrial nuclei. With the purpose of continuing this process of regeneration, a further shift of industrial activities towards other areas is required. As the port is in a constant state of transformation in order for it to grow and update its facilities but also to keep the city of Rotterdam profiting from its activities, one of the projects to support this is the development of the second ‘Maasvlakte’, an large size industrial area for effective and sustainable bulk handling, container terminals and distribution centers. It will entirely be built on reclaimed land on the coastline west of Rotterdam (Figure 2). With the creation of this ‘new land’, a substantial part of the industrial activities from the actual city ports can be relocated (and actually is being relocated at the moment), leaving space for transformation of the industrial area to a new urban neighborhood. In doing so, other parts of the Rotterdam city port can also now be redeveloped and to some extent gentrified, attempting to

create a high quality living and working area at the river bank; an area with a strong ambition regarding sustainability, that also will attract higher and middle income households that now often leave for Rotterdam's surrounding suburbs [27].

Figure 2. Overview of the Rotterdam city ports with the Merwe-Vierhaven ports indicated. To the left is the newly reclaimed land with new port known as the 'Maasvlakte' [25].



6.1. Rotterdam City Port Merwe-Vierhaven (MW4) Urban Renewal Program

The city port of Rotterdam is a diverse industrial area of about 1600 hectares. On the north side of the river Maas is one of its most attractive ports, the 'Merwe-Vierhaven' (MW4). This is the selected area for the research project presented (DIEMIGO 2.0), because of its advantageous location close to the center of the city, the manageable size of the neighborhood compared to the south part of the city port, good connectivity, need for climate adaptation strategies (necessary for the protection of surrounding areas) and because of its large shoreline that offers opportunities for both energy generation based on renewables and quiet urban living with integrated leisure activities. 'Merwe-Vierhaven' is the combined name for the 'Merwe'-port and the 'Vier'-port, of which the Vier-port is older with its commencement in 1916, *versus* 1930 for the Merwe-port. Both ports were functioning as storage and distribution centers for industrial cargo until many years later when both ports were together transformed into the Rotterdam Fruitport. Many quays are used for docking, although new functions have already entered the area (small creative companies and so forth). In its current situation, MW4 is the basis of the Rotterdam Fruitport, serving as a trans-shipment area for fruit and juice. However, over the coming years these activities will be moved to other quays in

Rotterdam, among them the Maasvlakte, so that MW4 can develop towards a new neighborhood of the city port.

According to the Rotterdam municipality, urban renewal in the MW4 port area may involve relocation of businesses, the demolition of structures, the relocation of people, and the use of eminent domain (government purchase of property for public purpose) as a legal instrument to take private property for city-initiated development projects. The Rotterdam city council has formulated a structural vision of how the neighborhood should look in three different time frames (2015/2025/2040). At the same time the challenges are to create [24]:

- Mixed program for urban functions to facilitate different activities in that area (working, living, recreating, *etc.*);
- Good sustainable connectivity to the city and the surrounding areas through variation in types of two-way connections (city part, city-district, neighborhood);
- Introduction of a mobility hub (not further elaborated in this paper) with convenient access via land and water (water bus and taxi) for public and private use as slow and fast means of transport;
- Introduction of sustainable water, sanitation systems (not further elaborated in this paper), which use the full potential of water, waste and energy related improvements (rain- and wastewater management as well as water supply);
- Creation of an energy effective and efficient built environment using the prospects of local energy production based on renewable energy;
- Possibility to create new building typologies, like floating houses and offices;
- Different types of buildings, both existing and new building stock.

The general, overarching aim of the transformation is to implement sustainability, to create a clean, green, healthy and attractive area. This sustainability can be found in energy neutral and climate proof buildings as well as sustainable energy systems [24].

6.2. Interconnection of Urban Program with Flexible E-Devices and Energy Generation Based on Renewables in the City Port MW4 Area

The problem is that although there is a potential abundant energy flow based on renewables, due to the urban layout based on alternating (former) docks, the consumption of energy is very concentrated at specific locations. The problem of concentrated energy demand pertains specifically for urban areas with (planned) densities above 35 households per square hectare [26].

In 2010 more than half of the world's total population lived in cities, and this share is expected to increase to 70 percent or more by 2050. The world's urban population is expected to increase from 3.5 billion in 2010 to 6.2 billion in 2050, and almost all of this growth is expected to take place in less developed countries, and above all in cities. Cities in developed countries will add only 160 million people to their populations during this period, while cities in developing countries will need to absorb 15 times that number, or close to 2.6 billion people, thereby doubling their total urban population. Given the expected decline in urban densities, these cities are likely to more than triple their developed land areas by 2050 [28]. This is while, since 1999, more than half of the world population already lives

on less than 4% of the world surface [29], which makes it a pattern for most of the (existing) developments aiming at fulfilling the energy demand based on locally available renewable sources. What is more is that these densely populated, urban areas are at the moment already responsible for roughly two thirds of the global primary energy demand [30]. Within the context of continuing urbanization, the demand of already high energy consuming areas will rise further the coming decades. The challenge thus not only lies in developing new energy efficient, possibly self-sufficient areas, but also in improving existing urban areas. Another potential obstacle that comes together with the increasing urban population and related energy demand is the high ratio of existing building stock that results in limited opportunities to achieve the necessary transformation in new expansions of cities alone.

The electrification of society continues strongly. At the moment most of this energy is still provided by fossil fuels. However, as is commonly known by now these supplies are decreasing and are also still causing many environmental problems. This requests for a changed energy mix based on locally available renewable sources (poly-generation) in combination with a flexible system of supply to users with bidirectional heat, cold and electricity transportation and attached storage facilities. Fortunately there are sufficient renewable energy sources available, like the sun and the wind.

By using these renewable sources a rising number of places around the world are achieving full closure based on renewables for their energy consumption [31]. A well-known example is the Danish Island *Samsø*. *Samsø* is the first energy self-sufficient island in the world that produces all its electricity with a combination of on- and offshore wind turbines and all its heat with a solar system and straw fired power plants. With this installed energy system the Island produces even more energy than it needs; it has become ‘energy positive’ so to say, an energy producer.

The excellent possibilities to integrate solar systems in buildings, together with limited available space elsewhere and large footprints of alternative renewable sources of energy, often results in a high percentage of solar energy systems in urban retrofit areas aiming at large fulfillment of energy based on renewables. Well-known European examples are the German town Freiburg districts *Vauban* and *Rieselfeld*, and the *Französische Viertel* (Südstadt) in Tübingen. Yet solar energy output, as many renewable sources output, is intermittent and unpredictable. The resulting fluctuations in energy transport cause stress in the grid because full capacity of the distribution cables might be needed to export excess energy at some times (high production, low demand) whilst in other moments energy demand might continue when no energy is being produced. To come to a reliable energy system it is therefore needed to implement an additional source in the system that can produce energy on an immediate start and stop basis. The problem is that to do so, a power plant needs to always be in a stand-by mode, which often results in a less energy efficient process.

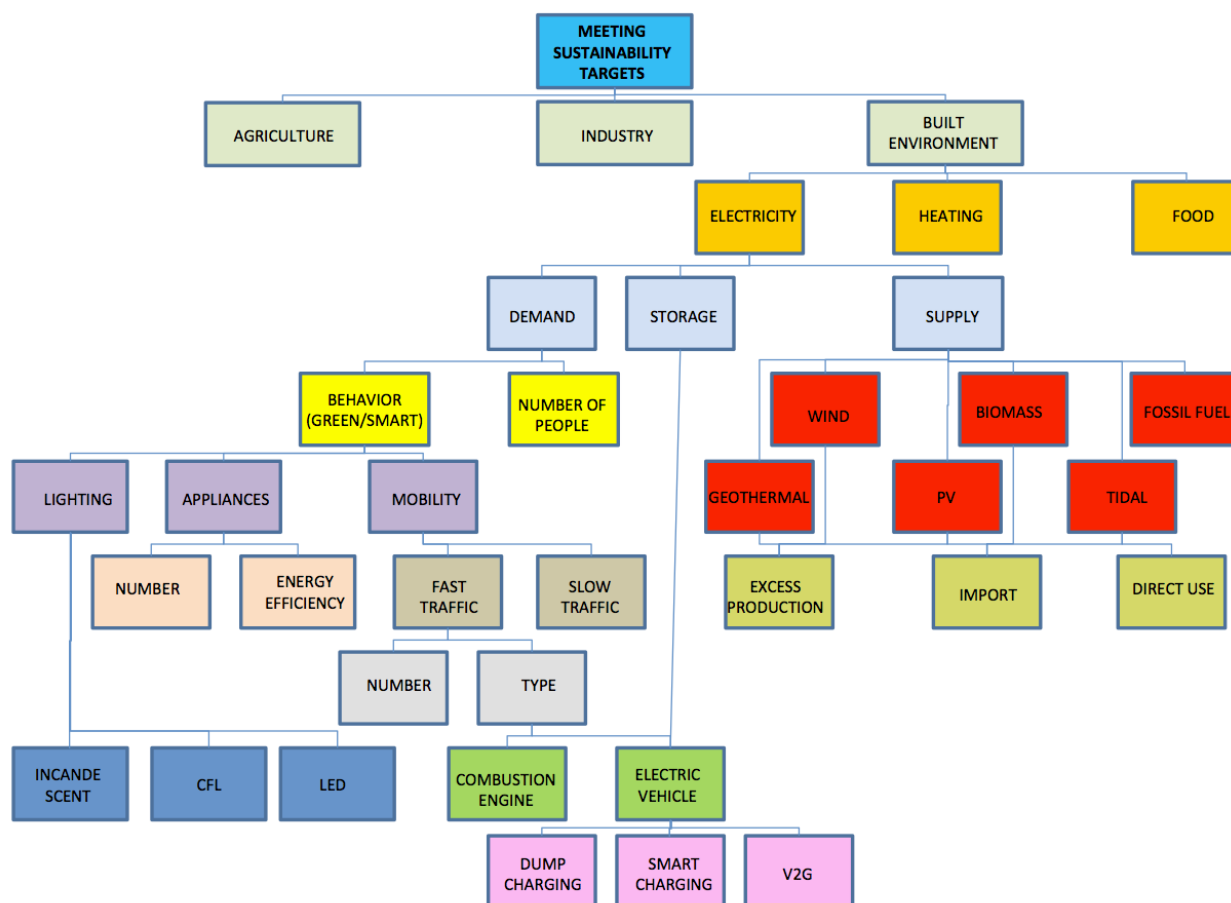
Alternatively, energy management achieved by demand side management or by the application of temporary storage devices can be used to reduce the stress in the grid. This energy management is already being encouraged in Germany with the introduction of a special tariff, approaching the feed-in tariff, for users with a photovoltaic system who can manage to match energy production and consumption in a way that they can self-consume all energy locally or in the immediate vicinity of the installation [32].

One of the most fundamental components of regenerating an urban environment is to understand the components of the area that are working effectively, to pin-point the negative aspects and to identify the opportunities available to activate the regeneration process. Such issues include connectivity

between buildings and spaces, access to the area from another public open space amenity, commercial activity, community facilities and housing density.

Since the specific aim of the city council with respect to the MW4 urban renewal is to create a sustainable, preferably energy neutral neighborhood, based on pioneering projects and inhabitants with partial urban gentrification, the research hypothesis of the presented sub research project was to pro-actively start with an energy based approach to find out what the building volume (program) and related prerequisites for the area redevelopment would be to fulfill this aim of the city council. This was also in continuation of previous research on different scales—varying from urban district, municipalities, city regions, to provinces [33–35]—that have shown that if energy is not taken as a starting point, it will be nearly impossible to achieve such far reaching goals during normal area redevelopment process, (or afterwards) in an economical way. Hence, research has to be done on alternative energy supply and consumption on the neighborhood and user scale. As many urban regeneration schemes involve developing a clear understanding at an early stage of the existing problems and potential future opportunities, this often requires focused consultation with both private and public sector organizations. Within this sub research project this has been done from the start. It formed the basis for the development of an initial brief into a full-scale design, taking into account ecological issues, community and stakeholder aspirations, urban utilities and services, transport constraints and planning guidance, but foremost sustainable transport strategies (the focus of the larger research framework DIEMIGO 2.0).

Figure 3. General framework of the presented research project, Rotterdam City Port MW4 [25].



In the MW4 area, the approach to create an energy balance in 2025 has been based on four steps of optimization: (1) energy consumption, (2) energy production, (3) load shifting in smart grids, (4) smart use of electric vehicles (EVs) and other flexible devices for energy storage (Figure 3). In close coherence to this, special attention has been paid to the neighborhood configuration that comes with different scenarios, and the yearly electricity import/export that results from the different energy systems. The stated four step approach, in fact, is strongly related to the well known ‘TRIAS Energetica’ (or: ‘Trias Ecologica’), which has been further developed in 2009 by the TU Delft for application in practice (known as ‘REAP’, Rotterdam Energy Approach Planning’ [36]). It is based on the skipping of the final step of the original TRIAS, while introducing a new in-between step.

The resulting ‘New Trias’ concerns: (1) Extending energy, water and material consumption; (2) Reusing waste flows; and (3) Filling in the remaining demand with renewables and applying a ‘waste=food’ approach. This ‘New Trias’ recognizes the importance of the urban metabolism approach with special emphasis on the site specific bio-climate or “genius-loci” related qualities and the importance of applying solutions and cycles as close as possible to the source of problems and demands.

6.3. Energy Saving and Energy Transition Potential

Within the TRIAS Energetica, REAP and many other strategies aiming at improving energy performance, energy saving has shown to be very important, and is also the first step within an energy-based approach of urban retrofit. Because of this, introduction (where possible) of more efficient devices and appliances, and better behavior of tenants in the neighborhood are discussed and form the basis of the energy conservation part of the research [37]. Besides this, the quality of the buildings that make up an area is still a key element in the success of regenerating an urban environment as well. In this sub research they lead together to the development of two different future energy consumption patterns that are tested on their influence on the energy balance.

Of the two different future energy consumption scenarios that are developed, the first is named the SMARTcity. It represents a society in which user comfort has a high value and it assumes a small growth in energy consumption between the present and 2025. The second future energy consumption scenarios is GREENcity which describes a society in which sustainability is considered very important, which leads to energy conservation techniques to be pushed. In fact, this lowers the consumption by up to 55% as compared to the SMARTcity scenario.

As stated, the overall aim of the sub research is to meet the sustainability targets as set by the (local) government. These targets ask for a transition at macro level but as Joore [38] indicates in his research on the mutual influence between new products and societal change processes, with respect to transitions there is a multilevel innovation perspective. Products in this case can be considered the smallest building blocks in an urban transition. New products can improve the process and in doing so, later can lead to learning effects to change the whole system and ultimately can lead to the desired transition [25]. The case study in this perspective focuses on three main points that together may readily alleviate the challenge of optimizing the energy balance:

- (1) Implementation of renewable energy systems in the area to produce clean energy.

- (2) Change of appliances on a user level (both in households—or clusters of households—and attached to households, e.g. EVs) in order to enhance more energy efficiency and thus reductions in the energy consumption.
- (3) Improvement of behavior, either by creating awareness or by the use of management systems that reduces unnecessary use of electricity.

The outcome of renewable energy potential resulted in the conclusion that solar energy (photovoltaic), biomass, wind and tidal energy systems are suitable for implementation in the MW4 area. Integration of urban agriculture has been investigated as well, with the result that livestock manure and algae have too little energy potential. At the same time tidal current turbines and wind turbines (legally allowed to be integrated in the area) are found to be too expensive and less effective (from a technological perspective).

From the selected energy systems, it was found that biomass, wind and tidal energy have to be given priority for implementation. This is because of the decreased stress on the grid in comparison with solar energy production alone. Yet it is important to notice that in this existing urban area still more than 90% of the supply will have to be generated from solar sources, as all other systems have a very limited capacity to be integrated in the existing retrofit area. Because of this high percentage of solar energy in the energy mix, the total energy that can be produced in one year varies greatly and correlates with the available roof surface/gross floor space ratio.

The first part of the research calculations of energy production and consumption for different scenarios, is based on a timeframe of one year. For the area, it is found that in case of only low-rise buildings (<3 floors on average) it is possible to balance the demand and supply in the area based on renewables, and without depending on surrounding areas.

The influence of electrification of heat for hot tap water and heating and of changing combustion engine driven vehicles (related to the district) for electric vehicles (EV) based modes of transportation have also been investigated. The result is 8 different configurations of the two main scenarios [25]:

- (1) Basic scenario
- (2) Basic scenario + hot tap water production with a heat pump (HTW)
- (3) Basic scenario + hot tap water production and heating with a heat pump (HTW&H)
- (4) Basic scenario + 10% EVs
- (5) Basic scenario + 100% EVs
- (6) Basic scenario + 10% EVs + HTW
- (7) Basic scenario + 10% EVs + HTW&H
- (8) Basic scenario + 100% EVs + HTW&H

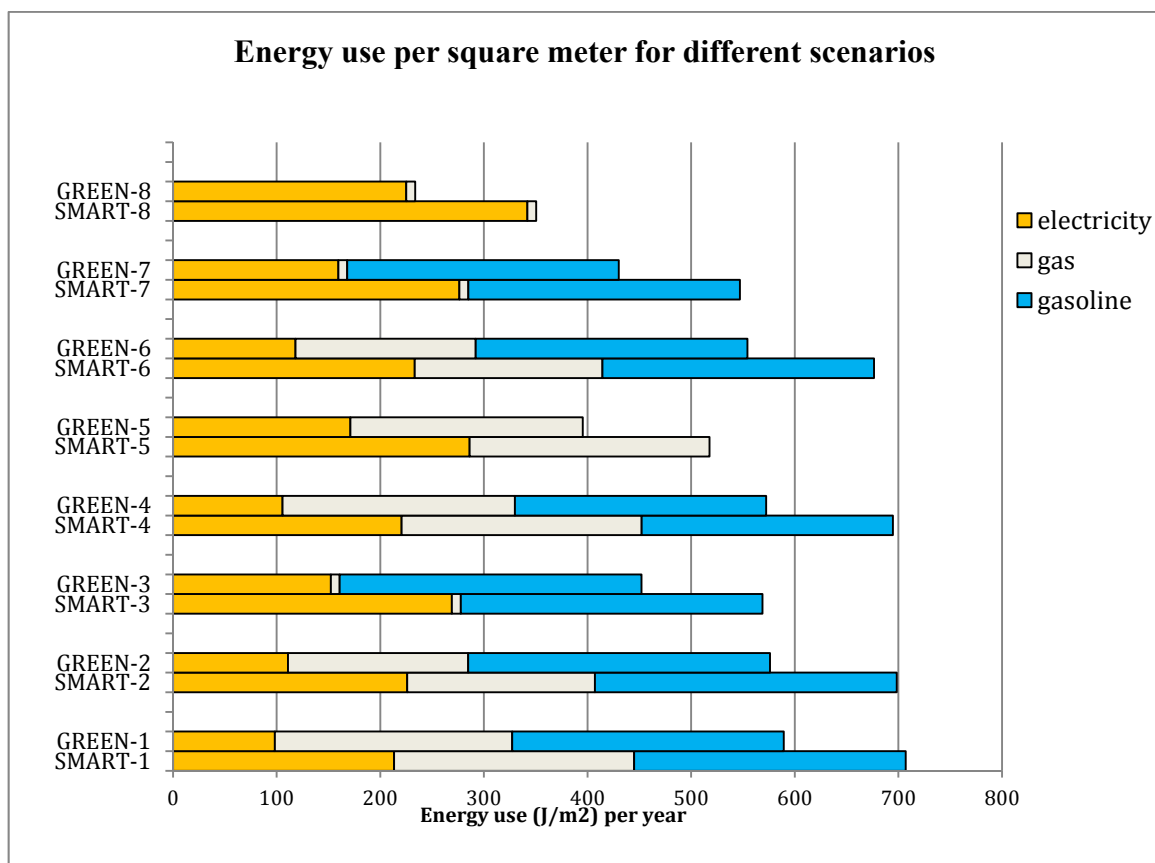
Any system used for the transition towards electrifying the energy demand for both heat and transportation (e.g. by EVs) results in a significant increase in electricity consumption. However, on the other hand, it does make the area more energy efficient, while the energy balance is relatively similar as well.

When both electrification of heat and transportation are fully applied, a household will use 60% less Joules per year (Figure 4). Yet this is not considered a very realistic scenario, as the additional systems needed increase the electric load in such a way that the living potential of the area is reduced significantly.

It is therefore advised that a moderate replacement of combustion cars (and other transportation modes) by EVs is encouraged, as well as the usage of heat pumps for hot tap water.

In this case, described by Scenario 6, increased energy efficiency was found in the GREENcity scenario to be 6%. Actually this is the most advantageous scenario found. In this elaboration the neighborhood can (on average) contain a little below 3 floors, while energy import and export is low (5.8 GWh/yr out of a total consumption of 11.08 GWh/yr), and therefore can be assimilated by existing infrastructures without much additional investments [25].

Figure 4. Energy demand per square meter built surface for the different scenarios [25].



In the second part of the sub research, hourly production and consumption profiles are developed, after which this obtained data is used as input for the EnergyPLAN model. EnergyPLAN is an energy system analyzing model (freeware), developed under the supervision of Hendrik Lund of the Aalborg University in Denmark, that can be downloaded at the EnergyPLAN website [39]. The model is basically a tool to help designing new, or analyzing already existing energy systems on a country or regional level. The EnergyPLAN analysis reveals that the area is not self-sufficient at all times. Moreover, even when a smart grid is implemented that can shift the load of flexible devices (both household appliances and EVs), only around half of the energy is directly consumed upon production. It implies that the neighborhood can be energy neutral on an accounting yearly basis, but it cannot be self-sufficient at all times, due to moments of peak demand and supply. So the MW4 area in these elaborations is not totally independent from surrounding areas. Yet especially in case of existing

neighborhoods in which the transformer capacity is limited, applying a smart grid is a useful way to minimize the critical export of electricity (loss) [13].

An interesting outcome, opposed to previous outcomes in the DIEMIGO research [26] is that using EVs as storage devices through ‘vehicle to grid’ (V2G) does not contribute to a significant optimization of the energy efficiency, when compared to a situation in which the EVs make use of smart charging. The difference is a result of the (mostly) residential character of the renewal program of the MW4 area, while the previous research mentioned considered a newly built commercial business area.

7. Conclusions

It is concluded that the best achievable energy balance in Merwe-Vierhaven (MW4) consists of an elaboration in which a smart grid is able to shift the load of flexible appliances and charge EVs via smart charging while energy generation is based upon biomass, wind, tides and the sun. In this configuration it is important to give priority for implementation to biomass production, wind and tidal energy systems. For a neighborhood with 1700 households this results in the possibility to build houses up to a maximum of 3 floors per building. The energy demand of the households and offices together add up to a calculated amount of approximately 11.08 GWh, of which around half is self consumed.

In order to optimize the potential of a neighborhood in an existing urban renewal context, it is most important to reduce the energy consumption (1st step in ‘TRIAS Energetica’ and REAP). When the present energy use is extrapolated to 2025, none of the scenarios (SMARTcity) in which the energy consumption and production in the neighborhood balance in one year, are considered realistic. The neighborhood in those calculations could host only a very small number of households, while in an energy saving scenario (GREENcity) this potential can indeed reach today’s cities average.

To optimize the energy balance of this urban renewal area, it is found to be impossible to do this by adapting the energy consumption (alone). Therefore, for this purpose it is found more important to change the energy mix. The problem in existing urban areas, however, is that often these areas are restricted to few (or even one) main energy sources; inside cities this often concerns integrated solar energy systems. But even in case of another mono-source based energy generation this limits the possibilities of local urban environments to be 100% self-sufficient at all times, even when such an area is being redeveloped, simply because there is no balanced choice as regard to the energy mix based on renewables. Possible solutions to still obtain a balanced energy profile can come from either the choice to not provide all energy locally, or adding different types of storage devices, other than those investigated in this research. Alternatively, self-sufficiency might be achieved on a different scale, such as city, province or countrywide. In general it can be said that the maximum living potential of an area with the goal to supply all its consumed energy with renewable energy sources, is most influenced by the energy consumption. But tuning the consumption can barely improve the energy balance. Therefore the determining factor in the energy balance is the energy production system.

Proponents have seen urban renewal as an economic engine and a reform mechanism, and critics as a mechanism for control. The use of energy balance based on renewables as a guiding principle is a new approach in the field. It may enhance existing communities, and in some cases result in both the saving and demolition of parts of neighborhoods which were not foreseen. In case of introduction of

new sustainable technologies, a protected environment for development (and first years of use and monitoring) is evident. As for system configuration, the choices arise mainly from technical and social optimisation. In fact the social, or user-related criteria will be decisive for enduring sustainability.

The introduction of solutions on an intermediate scale-level offers opportunities for elaborations in which (clusters of) buildings or even entire districts can be self-sufficient based on sustainable technologies while addressing best to user related awareness and participation. In doing so the following has proven to be essential:

- Respect all stakeholders, especially (end-)users. This goes for the design and development phase, as well as for the application and use-related phases;
- Take a positive approach when addressing sustainability issues (or as Jaime Lerner states it: “When you project tragedy, you find tragedy” [40]). A positive approach influences the attitude of people towards the (radical or not-) plans and in doing so allow improved level of ambition;
- Make changes simple and realise tangible effects at short notice. All people desire improvement (especially environment related), however few people like to change;
- Take care of an integrated approach; not only for different essential services and ‘flows’ (water and energy supply, waste management, *etc.*), but also of policy-legislation, security and responsibilities and spatial planning, liveability and economical development); and finally,
- The human scale is unique, try to address as much to this scale level of implementation as possible.

Conflict of Interest

The authors declare no conflict of interest.

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