Towards CO₂ Neutral City Planning
—the Rotterdam Energy Approach
and Planning (REAP)

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Summary

By the year 2025 the city of Rotterdam, with the largest port in Europe, aims to reduce its CO₂ emissions by half, an ambitious plan that will require a revolutionary approach to urban areas. One proactive response to this challenge is an exploratory study of the Hart van Zuid district. An interdisciplinary team has investigated how to tackle CO₂ issues in a structured way. This has resulted in the Rotterdam Energy Approach and Planning (REAP) methodology. REAP supports initial demand for energy, propagates the use of waste flows and advocates use of renewable energy sources to satisfy the remaining demand. REAP can be applied at all levels: individual buildings, clusters of buildings and even whole neighborhoods. Applying REAP to the Hart van Zuid district has shown that this area can become carbon neutral. Most importantly, REAP can be applied regardless of location.

Key Words: REAP, Rotterdam Energy Approach and Planning, carbon neutral city planning, closed cycles, sustainability, sustainable urban planning, sustainable architecture, urban development.

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1 INTRODUCTION

1.1 Prospects for the Future

Ten years ago few people thought that the climate was changing and even fewer realized that mankind was influencing the change. Since then opinions have altered and now the world is generally convinced of the seriousness of the situation: the climate is changing at an unprecedented rate, mankind is one of the major causes as acknowledged by the IPCC [1] and fossil fuels are rapidly depleting. Because of this, attention is concentrated on energy consumption and the consequences of this. However, there are other forms of damage to both the environment and public health that must not be ignored. It is possible to arm ourselves against, or if required to flee, the consequences of climate change. However the biggest social problem is not climate change but the depletion of energy reserves; a socio-economic problem rather than a technical one. This will have far reaching consequences for what can and cannot be achieved. Industrialized nations are highly dependent on the easy supply of fossil energy. Just before the start of the current world-wide economic crisis the price of oil reached a previously inconceivably high level (nearly 145 USD a barrel) and, at the time, experts expected the price to double. A price of more than 100 USD a barrel has serious consequences, which could be seen in the reduction in sales of petrol guzzling SUVs in America. Energy affects everyone, but especially the poor and the people living the farthest away from amenities. Already by 2010 the price of oil had again reached a level of $110 a barrel. It would be wise to use the present crisis as the impetus to develop a different energy system.

1.2 Energy

The energy crisis does not mean that individual countries have to cut themselves off from the outside world and only use energy that can be generated within its own borders — even if that were possible — but it is wise to make better use of within-country energy potential. The continental area of the Netherlands is sufficient to generate enough solar energy to supply the economy of the whole world [2]. Technically it is possible to realize a completely sustainable energy system but, for the time being, costs are prohibitive. A current requirement is an assessment of resources and intelligent methods for using them appropriately. In built-up areas it is important to target the following measures:

1. Applying renewable energy sources. Within the foreseeable future there will simply be no other sources.
2. Making use of the available energy potential. This is an interpretation of the first measure at local level: renewable energy could be imported but it is far better to make use of local opportunities.

3. Making better use of waste streams. All buildings and urban areas generate waste flows that could be harnessed but rarely are. Making use of these waste flows would reduce the primary demand and so aid the introduction of sustainable energy sources.

4. Intelligent and bioclimatic design of buildings. This refers to making intelligent use of local conditions — climate, soil and environment — in the design of buildings and districts. Buildings and neighborhoods are no longer seen as objects out of context.

5. Energy savings in existing buildings: this will continue to be necessary as in 2025 (the period by which the city of Rotterdam must have halved its CO$_2$ emissions) around 90% of the built-up region will be made up of the buildings that are here today and which are frequently far from energy efficient.

### 1.3 The Three Stepped Strategy for Energy

Since the end of the 1980s sustainable approaches to urban areas have followed the three step strategy (see Figure 1):

**Step 01** Reduce demand

**Step 02** Use renewable energy

**Step 03** Supply the remaining demand cleanly and efficiently

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**Figure 1**

The Trias Energetica, the Three Stepped Strategy for Energy [3]
This strategy towards energy use is known as the Trias Energetica [3]. It forms the guideline for a logical, environmentally conscious approach but in the twenty years that it has been in use, it has not led to the required sustainability. In particular, the degree of penetration of renewable energy sources, Step 2, has been minimal. Sustainable building in the Netherlands mainly concentrates on Step 3 which, in practice, is often mixed up with Step 1. The Netherlands, which has been using the Trias Energetica since the early 1990s, has a very limited use of solar, wind and other renewable energy technology in comparison with other European countries. This is probably related to the Trias Energetica. If Step 2 abruptly follows a sub-optimal reduction in energy demand in Step 1, a great demand for energy still needs to be met by renewable in Step 2, which so far has been economically unfeasible. In practice this leads in quick succession to Step 3 – the use of traditional, albeit more efficient, technology. Hence, in our opinion an important intermediate step, which would make the use of renewables better feasible, has not been explicitly mentioned.

1.4 The New Stepped Strategy

The New Stepped Strategy adds an important intermediate step in between the reduction in demand and the development of sustainable sources, and incorporates a waste products strategy [4] (partially inspired by the Cradle-to-Cradle philosophy [5]):

Step 01 Reduce demand (using intelligent and bioclimatic design)
Step 02 Reuse waste energy streams
Step 03 Use renewable energy sources and ensure that waste is reused as food
Step 04 Supply the remaining demand cleanly and efficiently

FIGURE 2
The New Stepped Strategy, Inserting a Step and Omitting the Last Step of the Trias Energetica [4]
FIGURE 3
The New Stepped Strategy at the Building Level [4, 8]
As can be seen, the New Stepped Strategy has a new second step that makes optimal use of waste flows — waste heat, waste water and waste material — not only for each individual building but also on a city-wide scale. Waste flows from one chain may be used in a different chain. For example, waste water can be purified and the silt fermented to form bio-gas which can be reused in the energy chain. The addition in step 3 (really 3b) concerns waste that cannot be processed in a technical waste processing cycle and so must be returned to nature. This can only be done if the waste is safe (non-toxic) and if it can form nutrients for micro-organisms.

Step 4 will continue to be necessary for the coming years, but eventually this will no longer be possible or desired when all energy in the built environment can be produced by renewables. The development of new areas or the redevelopment of existing areas should already take this into account because the fourth step will remain a painful necessity in many other regions.

1.5 Old Energy System Versus Sustainable Energy System

Considering the organization of the energy system, by 2010 only 96% was generated from fossil or nuclear sources but at the same time a lot of heat is lost (in the air, water or ground) and many potentially useful by-products are wasted. A source such as natural gas is delivered to all public and private amenities. Taking the quality of energy into account (exergy) this is a significant potential loss of energy. A gas flame of 1,200 – 1,500°C is much more appropriate for high-grade industrial processes (that actually require such high temperatures) than for heating a home to 20°C. If homes are intelligently designed then a temperature of 25 to 40°C is more than sufficient for the heating; this temperature is released as waste heat by many kinds of processes (e.g. greenhouses or cooling systems in offices). Other amenities require higher temperatures, but these could be achieved using waste heat from other higher-grade processes. A more sustainable system based on the usage of this waste would require significantly less primary energy and this primary energy would only be used by the most high-grade functions (a low-exergetic system) [6]. Although not an efficient system, it can be very effective: sustainability could be theoretically increased six-fold, while the current plans for improvement may only increase efficiency by as little as 10%.
2 THE REAP METHODOLOGY

2.1 From Building to Neighborhood

If the New Stepped Strategy is applied to an individual building it will undoubtedly generate a more sustainable building, but within the whole urban context this would be a waste – or a missed opportunity. No use is made of the direct surroundings. The energy demand per building can, and must, be reduced. After this it is useful to determine whether waste flows from the building can be usefully employed. This is already being done, for example, by recycling heat from ventilated air and waste shower water. However, it is much more difficult to purify wastewater from each building to reclaim bio-gas. In short: after step 2 a significant demand for energy remains which, according to step 3, must be solved using renewable energy sources. As has already been mentioned, this is technically possible but requires huge investment. A better idea is to consider a cluster of buildings and to determine whether energy can be exchanged, stored or cascaded (see schematic diagram). In other words, if at individual building level all the waste heat has been recycled, the remaining demand for heat or cooling can probably be solved by buildings with a different pattern of energy requirements, buildings with an excess of the required energy or which produce waste heat (or cold).

1. An example of exchange: due to internal heat production, modern offices start cooling as soon as outdoor temperatures exceed 12ºC. At these temperatures homes still require heating. This provides opportunities for heat exchange during spring and autumn. Another example is the combination of supermarkets (always cooling) with homes (frequent heating).

2. An example of energy storage at cluster level: heat and cold are only available in excess when there is little demand for them. For an optimal energy balance, energy should be stored during seasons when the exchange, as mentioned in example 1, is not required.

3. An example of cascading: a greenhouse captures much passive solar energy which usually disappears as waste heat into the air. A heat exchanger could enable this waste stream (usually about 30ºC) to be used to heat homes, provided these homes are well insulated and make use of a low-temperature heating system. If all waste flows at cluster level are being used optimally it then becomes possible to see if primary energy can be generated sustainably. Although solar panels, solar collectors, or a heat pump with a ground collector system can be installed in each individual building, it is much more economical to set these up at cluster level.
2.2 From Neighborhood to District

If a project can be tackled at an even higher level, such as district level, potential discrepancies in the energy balance at neighborhood level (for example excess demand for waste heat or cold) may be solved. At district level it is reasonable to assume that other functions are available with a totally different demand, and therefore, supply pattern. And just as at cluster level, it is also possible to exchange, to store and to cascade energy (see the schematic diagram of Figure 4). Certainly at the larger amenities, such as shopping centers, swimming pools and concert halls, the energy pattern is so specific that by combining a number of these different amenities it is likely that an energy balance can be achieved. Hart van Zuid provides good opportunities for this.

In addition to exchange, storage and cascading, another option is possible at neighborhood level: energetic implants. This is an intriguing term for adding a function to complete missing links in the energy supply chain. Once the existing amenities in the area have been optimally tuned to each other (here, as an example, only the heat balance is considered) a residual demand for heat or cold (but not both) will still exist. In this case it is only necessary to look for an amenity that requires extra heat (for example, a swimming pool) or cold (for example, an ice rink) on a yearly basis. The provision of renewable energy can then be tackled at district level. As has already been said, some sustainable measures can be implemented at building or neighborhood level, but other more capital intensive projects are more appropriate at district level. An example of this is the bio-gas fermentation installations that recycle bio-gas from wastewater and use power-heat coupling (CHP) to generate heat and electricity. Geothermal energy is also only feasible on a grand scale.

2.3 From District to Entire City and Beyond

The next step to a higher level would be the city or region, the scale in which our current amenities are generally centrally regulated. In the city of Rotterdam the city heating network is fed with waste heat from the electricity generators. City heating provides heat at temperatures between 90 and 130°C. This is perfect for old buildings which are poorly insulated and with central heating systems based on 90 to 70°C. However, in new housing projects the buildings are much better insulated and would be better served with a heating system based on lower temperatures, such as floor and wall heating using temperatures lower than 50°C. Most modern homes would even be fine with temperatures lower than 30°C. City heating is unnecessary for these buildings. Once a connection to the city heating is necessary or desired, the whole exercise of exchange, storage and cascading at neighborhood and district level is no longer necessary (see Figure 5). In that case the city heating takes care of the heating and potentially also the cooling (via absorption cooling).
The problem with this is that the local waste heat can no longer be made useful and disappears into the environment — the urban or natural surroundings. Given the climate change expected worldwide and in cities [1, 7] — in which cities will become warmer, both directly and indirectly — this situation is not desirable. For this reason the REAP methodology aims first at solving the problems of energy demand and supply on a small scale, after which ‘help’ can be called in from higher levels. In addition, the city heating can fulfill a useful role as a backup system, or as a loading and unloading system for heat imbalances in a district or neighborhood. REAP can help make an existing neighborhood sustainable, without requiring drastic urban planning measures. The following chapters will not only show that this can lead to carbon neutral neighborhoods but also how this can be done [8].

FIGURE 4
The REAP Methodology

Normally the process would start with the two steps at the lower left corner, with energy renovation of existing buildings (firstly reducing the demand, secondly adding heat-recovery systems). Instead of immediately proceeding to supplying the remaining demand through renewables, it is more effective to study whether exchanging energy with the built environment is an option, either the neighborhood or district, before solving the final demand by renewables at all scales. [8]
3 THE CASE OF HART VAN ZUID

How can REAP be applied to an existing, complex urban area — in this case, the Hart van Zuid district? Which decisions within the methodology must be made if the desired reductions in CO₂ emissions are to be achieved — decisions at economic, political, public, urban development and architectural level? And what are the consequences for the buildings in a city and the open spaces in between? In addition, the examples explicitly look for combinations of measures for CO₂ reduction, together with sustainable development.

How can this cluster, with its mix of 1960s urban development and 1980s architecture, once again become attractive in and for the city? It is currently mainly a shopping centre, attracting people from the south of the city, with an unusual mix of infrastructure (e.g. the second busiest bus station in the Netherlands) and a theatre, but with no activities after opening times and no links to the surrounding areas. At the same time, the buildings devour energy; heating in the winter and cooling in the summer. How can this urban development problem, coupled with Rotterdam’s CO₂ targets, be transformed into a future-oriented, attractive development?
Step 00 Make an inventory of the current energy demand.

Step 01 Reduce the demand > New functions will be added: 20,000 m² shops, 6,000 m² supermarket. Theatre Zuidplein and the infrastructure intersection will be renewed. Better insulation of the existing shopping centre will in itself already significantly improve the situation.

Step 02 Reuse of waste flows > The addition of housing will create a better heat-cold balance. The use of the waste heat generated by the supermarket and the typical morning and evening energy demand in homes means that the match is perfect: 1 m² supermarket can heat 7 m² of housing! If 665 apartments are added, the heat-cold ratio becomes 1:1.08 assuming that use is made of heat and cold storage (Figures 6 and 7).

Step 03 Renewable energy generation > The remaining demand for heat can be solved by the addition of greenhouses on the first floor. These could be public areas (or greenhouses for growing tomatoes) or by the addition of PVT-panels. PV panels could also be installed on the roof to supply electricity for the whole shopping centre. The remaining energy required could be sustainably generated at a higher scale level. (Figure 8)

FIGURE 6
Summer Situation: Energy Demand of the Total Program, Heat (H), -865 GJ, Cold (C) -5475 GJ, Electricity -7034 GJ [8]
FIGURE 7
Winter Situation: Energy Demand of the Total Program, Heat (H), -7788 GJ, Cold (C) -1755 GJ, Electricity -7595 GJ [8]

FIGURE 8
Energy Balance and Remaining Energy Demand to be Solved at a Higher Scale [8]
3.1 Motorstraat Area in the Hart van Zuid District

In this area with a school and some smaller businesses, the aim is to build two new colleges on the redeveloped Motorstraat ('Motor Street'). This provides an opportunity for developing a balanced, multi-functional cluster. But which functions can be sustainably combined, taking energy, social and economic issues into account?

A combination with housing improves social integration in the area by ensuring that the area is used throughout the day. Adding offices strengthens this mix. To achieve an energy balance in this cluster the intended 50m Hart van Zuid swimming pool can be combined with a new ice rink. The waste heat from the ice rink in combination with the swimming pool's permanent demand for heat provide an opportunity for using thermal storage to create energy balance. The remaining demand for heat can be satisfied using a combination of solar collectors and greenhouses.

**Step 00** Make an inventory of the current energy demand  
This is to be a newly-built area so right from the start the perfect function mix can be set up. New functions are added to the cluster based around two new intermediate vocational colleges.

**Step 01** Reduce energy demand  
The most up-to-date techniques in energy saving will be used (Figure 9).

**Step 02** Reuse waste flows  
Balancing the heat-cold relationship by the addition of functions: 50 m swimming pool (permanent need for heat), ice rink (permanent need for cooling) as well as homes and offices (Figures 10 and 11).

**Step 03** Renewable energy generation  
The resulting demand for heat can be completely satisfied by the addition of solar collectors on the roofs and the incorporation of a greenhouse in between the various functions. This greenhouse will also provide an additional (productive) space. Any remaining energy requirements will be sustainably generated at a higher scale level (Figure 12, 13 and 14).

The cluster as a whole will become a highly efficient complex with a constant daily use and bustling with life, both on weekdays and in the weekend. It will radiate a positive charisma affecting the whole neighborhood (Figures 15 and 16).
FIGURE 9
Step 01

STEP 01: reduce energy consumption through insulation - by balancing heat and cold demanding program

PROGRAM

01  300 houses  21000 m²
02  school  17000 m²
03  ice rink  20000 m²
04  swimming pool  7000 m²
05  offices  11000 m²

total cluster  78000 m²

FIGURE 10
Step 02, for Summer

STEP 02. H : C balance per program

SUMMER

Energy demand total program
H  7.80 GJ
C  13.03 GJ
E  6.40 GJ
FIGURE 11
Step 02, for Winter

STEP 02: H. Climatic per program

WINTER

Energy demand total program

H = 18.946 GJ
C = 7.48 GJ
E = 8.746 GJ

FIGURE 12
Step 03

STEP 03: resulting heating demand sustainably generated by greenhouse and solar collectors

SUMMER

solar collector

greenhouse
**FIGURE 13**
Energy Balance and Energy Demand

<table>
<thead>
<tr>
<th>Step 01</th>
<th>Step 02</th>
<th>Step 03</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce energy demand through insulation</td>
<td>H : C balance total cluster Heat - Cold ratio H / C</td>
<td>Resulting heating demand sustainably generated by greenhouse and solar collectors + renewable energy generation</td>
</tr>
<tr>
<td>total demand cluster:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>C</td>
<td>E</td>
</tr>
<tr>
<td>36,341 GJ</td>
<td>-21,106 GJ</td>
<td>-12,245 GJ</td>
</tr>
<tr>
<td>thermal storage cooled heating demand</td>
<td>21,106 GJ</td>
<td>5,825 GJ</td>
</tr>
<tr>
<td>resulting demand</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>extra electricity demand due to usage greenhouse</td>
</tr>
</tbody>
</table>

**ENERGY**

| contribution PV panels | 1.361 GJ |
| resulting energy demand | 12.047 GJ |
| demand: | |
| H | C | E |
| 0 GJ | 0 GJ | -12.047 GJ |

**FIGURE 14**
Energy Flow Diagram

![Energy Flow Diagram](image)

- **H**: heat
- **C**: cold
- **E**: electricity
- **01**: housing
- **02**: asphalt
- **03**: swimming pool
- **04**: ice rink
FIGURE 15
Programmatic Section

FIGURE 16
New Overall Plan with Mixed Program with Optimal Energy Exchange
4 CO2 MAPPING

REAP provides a structure for CO2-intelligent development of a particular area. If CO2 issues are to play a role in spatial design and development then sufficient knowledge of the various possibilities must be available. At each step it must be clear what is actually feasible. The CO2 map has been developed to provide such an insight. The CO2 map gives a picture of the current situation and provides a toolbox for CO2-intelligent developments for the area (Figure 17).

In reality the CO2 map is much more than just a map. It is an instrument providing information for each aspect of REAP in the form of maps and background information. Aspects related to energy saving and renewable energy production are in the form of a geographical map coupled to a GIS-system. All aspects, in particular those related to energy exchange, are in the form of generic information concerning CO2-intelligent opportunities.

The maps related to energy saving and renewable energy production (Figure 18) show the current potential at cluster level. There is an overview of which functions are present at each cluster. In addition, for each separate cluster the map shows how much energy could be saved and the amount of renewable energy that could be produced — heat and cold storage, urban wind, solar electricity and solar heat collection. Whereas the maps visualize the CO2-intelligent potential for the current situation, the toolbox gives guidelines for demolition, new building or additions to the program. Such new developments benefit from the generic information in the toolbox. It is even possible to modify the building program based on REAP and in particular on the information in the toolbox. For the first step the toolbox indicates the potential minimum energy consumption per m² — and thus the potential energy savings compared to the current situation — that is feasible for the different amenities. The generic information for the third step is an overview of the pre-conditions for the implementation of various forms of renewable energy production per building — heat and cold storage, urban wind, solar electricity and solar heat collection. The generic information in the toolbox for the second step is an overview of the consumption of electricity, heat and cold per m² for the different amenities.

This can be used to determine which functions can be combined energetically — demand and supply of heat and cold — for energy exchange within the program. It is also possible to determine whether it would be beneficial to incorporate an extra function in cases where the demand and supply do not match.
FIGURE 17
CO₂ Reduction, Energy Flows and Renewable energy [8]

FIGURE 18
CO₂ Map with Reduction Potentials as a Result of Insulation and Other Existing Solutions [8]
5 CONCLUSIONS

The general aim of this study is to discover whether CO₂ neutrality can be achieved within an existing part of the city, working from the urban planning and spatial design processes. A manageable method is arrived at based on the guiding principle of reduction of both energy demand and CO₂ emissions. Further, REAP is based on a realistic approach to economic, social, political and organizational structures. The following points summarize the advantages and limitations of the REAP methodology in CO₂ neutral urban planning.

5.1 Other Architectonic Styles

The use of REAP has been worked out and depicted in areas and buildings (existing, remodeled and new) with a particular style. The REAP methodology is, however, architecturally independent and allows for different solutions – and the associated different architectural expressions.

5.2 Energy Techniques

An inventory of energy production on a city-wide scale shows that some techniques are potentially much more profitable than others. This, however, does not mean that the less profitable techniques are not useful in the development of individual buildings. Although it would appear that wind induced energy in an urban area is of little significance, an effective combination of high rise building and wind turbines is still possible. This, however, is beyond the scope of this study.

5.3 Financial, Economic and Organizational Aspects

Designs for the 2020s are based on the current (affordable) technologies. An in-depth study of financial-economic and organizational aspects goes beyond the scope of this report but a few recommendations can be made:

- Develop a joint sustainability target for a particular area together with instruments such as a sustainability index.
- Stimulate the different parties with benefits such as tax rebates to guarantee that targets are met.
- Ensure that the time factor is taken into account. The best (financial) solution for a particular situation changes with time.
- Develop new structures so that parties can attune energy supply.
- Develop new instruments to guarantee the delivery of energy.
5.4 Ideal Solutions Versus Time

The search for the perfect solution at the right place depends on different guiding factors — money, technology, organization, information — which all change with time. In the near future this can lead to a completely different solution to the one suggested in this study. Recently it has become increasingly clear that the choice of projects is mainly determined by economical considerations, together with the available energy techniques. Financially this depends on energy prices, availability of money and potential subsidies. This serves to underline the fact that there are no ideal solutions, at most they are only temporary; the best combination of measures is continually changing. Nevertheless it is essential to gather more information and gain an insight into the principles involved. When solving issues of renewable energy production, and in particular up-scaling production, it is essential to relate to each individual situation and the above mentioned aspects such as time and money. For each step in the REAP-methodology, it is useful to know which financial and organizational aspects are involved so that a well thought-out decision can be reached.

A critical note can be made regarding the new necessary infrastructure. As this is different from the existing energy infrastructure new investments have to be made. Also, carbon neutrality goes beyond heat and cold; in particular, the generation of sustainable electricity is difficult and has to be addressed. Apart from other issues which go beyond the scope of this article, as food and materials, mobility must be included. Radical changes in public and private transport are needed.

5.5 CO₂ Neutral Urban Development is Possible!

After applying REAP to Hart van Zuid, calculations have shown that CO₂ neutral urban development within the built up area of an existing city region is possible. That is why we, the authors, would like to encourage the reader to always consider where possibilities for small-scale energy exchange lie so that a gigantic effect can be achieved on a much larger scale.
References