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Comprehensive Approach to Energy and Environment in the Eco Care Program for Design, Engineering and Operation of Siemens Industry Solutions

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Abstract

This paper intends to describe the outline of the Eco Care Program (ECP) at the Siemens-Division Industry Solutions and its implementation. ECP aims to embrace and to coordinate main activities within the product lifecycle management (PLM) process considering both economic targets in terms of overall lifecycle costs as well as energy efficiency and other important environmental issues in the innovation management for industrial solutions. ECP consists of adapted methods for assessing the environmental and financial impacts of industrial solutions (plants, processes, single technologies or even services) and tools which helps to derive reliable assessment results. Life Cycle Assessment (LCA) is a suitable method for assessing environmental impacts of products and solutions over their entire lifecycle focusing on those lifecycle phases which may contribute significantly to environmental burdens or benefits. To meet these requirements the main challenge is to simplify the assessment methodology as far as reliability and accuracy of results is preserved.

To present results in both dimensions of economical performance and environmental impact the paper introduces the concept of the “eco care matrix” (ECM). Environmental sound industrial solutions have advantages in both “eco” dimensions (eco-nomical + eco-logical). The analytical approach presented is further on implemented in two complementary and independent industrial application fields: in order to exemplify usability of the approach in quite complex process technology different hot metal producing technologies (blast furnace route vs. smelting reduction routes COREX / FINEX). The second pilot application is targeted on the assessment of infrastructure solutions especially focusing on the comparison of environmental and financial effects of different technologies and payment schemes of electronic city tolling systems for London and Copenhagen. Experienced results derived from these two pilot applications to put ECP in place are evaluated and presented.

1 Introduction

The Siemens-Division Industry Solutions is one of the world-leading solution and service providers for industrial and infrastructure facilities. The product portfolio of Industry Solutions contains already a high number of energy efficient and environmental sound solutions. The Eco Care Program (ECP) at Industry Solutions has the objective to increase the amount of environmental sound products / solutions, i.e. green products / solutions significantly in the product portfolio. For that purpose the existing Product Lifecycle Management (PLM) process has been extended towards a “Green-PLM” (ref. to [1]). The application of the Green-PLM will be shown in two case studies:

- Industrial Case: Steel Plant
- Infrastructure Case: City Tolling

2 Methodology

2.1 Life Cycle Assessment (LCA)

LCA has been developing since the 1980’s. In the beginning primarily in scientific fora such as Society for Environmental Toxicology and Chemistry (SETAC) but later the development has been taken so far that the International Organisation for Standardisation (ISO) and other international and national organisations and authorities have developed standards and guidelines (e.g. ISO-14040: 2006 Environmental management -- Life cycle assessment -- Principles and framework; ISO-14044: 2006 Environmental management -- Life cycle assessment -- Requirements and guidelines).

The **goal and scope definition** concerns specification defining the scope of the study. What questions intends to be answered by the study and which decision

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should it support. A crucial point in LCA is the use of a functional unit which serves as the reference for the assessment, e.g. 1 ton of hot metal - or for a paint; e.g. the protection of a $10m^2$ surface for 10 year. The system boundary determines which unit processes are included in the LCA and must reflect the goal of the study. The intended data requirements are also described. Finally the goal and scope phase includes a description of the method applied for assessing potential environmental impacts.

The **life cycle inventory** concerns the collection of data for inputs (energy, materials etc.) and outputs (products, waste, emissions) for each of the processes that are included in the study. All data are aggregated into one number for each input/output, e.g. the amount of CO_2 emitted in each process is summed into one figure in the inventory.

The third phase **'Life Cycle Impact Assessment'** is aimed at evaluating the contribution of each of the inventory items to impact categories such as global warming, acidification etc. Normally around 10 categories are assessed: Global warming, ozone depletion, acidification, photochemical ozone formation, eutrophication, toxicity to humans, ecotoxicity, land use, some solid waste, and resource use. **Characterisation** is the first step, in which the contribution of each inventory item to each impact category is calculated using the characterisation factors of an impact assessment methodology. Characterisation factors are often expressed as an equivalent of a substance, e.g. for global warming CO_2-equivalents are used. Different substances contribute to different extent to the impact, for example methane (CH_4) has a global warming potential that is 25 times larger than CO_2, i.e. 25 CO_2-equivalents and nitrous oxide (laughing gas) has a potential of 250 CO_2-equivalents. In this way 1 kg of methane and 1 kg of nitrous oxide can be summed to 275 kg CO_2-equivalents. The next steps are **normalization** and **weighting**, but these are both voluntary according the ISO standard. Normalization is often expressed in person-equivalents i.e. what is the contribution of the assessed system compared to the total contribution of one person per year to that impact category. The normalisation provides a basis for comparing different types of environmental impact categories (all impacts get the same unit, person equivalents). The seriousness of the impacts can be taken into account through weighting. Weighting of the results can be done in different ways e.g. expert panels, questionnaires or as distance to politically set reduction targets. With the current global concern for climate change it is plausible that global warming would receive a higher weighting than for instance photochemical ozone formation, which is a local/regional impact. Weighting of the results would change the environmental profiles of the different systems analysed and probably also the difference between them.

The **'interpretation'** phase relates the results to the goal and scope. An analysis of major contributions, sensitivity analysis and uncertainty analysis leads to the conclusion whether the ambitions from the goal and scope can be met. More important; what can be learned form the LCA? All conclusions are drafted during this phase. Sometimes an independent critical review is necessary, especially when comparisons are made that are used in the public domain (ref. to [2]).

The European Union is in the process of developing The “International Reference Life Cycle Data System” (ILCD) for good practice in LCA with aim of ensuring comparable and quality-assured LCA studies and applications in business and the public sector. The ILCD includes handbooks with requirements on method, quality, nomenclature, documentation, and review. Plus supporting documents and tools. And it goes a little further in the specifications than the ISO standards (refer to the European Commission homepage for Life Cycle Thinking in reference [3]).

Also the United States have developed a reference document for LCA. The LCA101 document from 2006, entitled "Life Cycle Assessment: Principles and Practice," provides an introductory overview of LCA and describes the general uses and major components of LCA. They also developed a Life Cycle Impact Assessment methodology (TRACI) that is widely used in the US. All US EPA documents on LCA can be assessed (ref. to [4]).

The United Nations Environment Program, UNEP and the Society for Environmental Toxicology and Chemistry, SETAC launched an International Life Cycle Partnership, known as the Life Cycle Initiative, to enable users around the world to put life cycle thinking into effective practice. The mission of the Life Cycle Initiative is: “To develop and disseminate practical tools for evaluating the opportunities, risks, and trade-offs, associated with products and services over their whole life cycle.” The Life Cycle Initiative does not as such produce guidance documents but merely aims to further the use of life cycle thinking. At their website a range of documents related to LCA can be found (ref. to [5]).

In many other places around the world national initiatives for building up LCA competences has been initiated. At the Life cycle initiative website a good overview can be found, but one of the most noteworthy is the LCA project in Japan, which is as far or even further than the European and US initiatives. More information about this can be found the homepage of the Japanese Environmental Management Association for Industry (JEMAI, ref. to [6]).

2.2 Eco Care Matrix (ECM) within Green-PLM

The development of green products / solutions has become very important due to the climate change. Looking at the existing PLM processes used in many companies worldwide a methodology to support the design of green products / solutions is missing. To close this gap in the PLM methodology the Eco Care Matrix shown in figure 1 has been derived based on a former approach from BASF (Eco-efficiency Analysis, ref. to [7]). The combination of ECM and PLM leads to the Green-PLM.

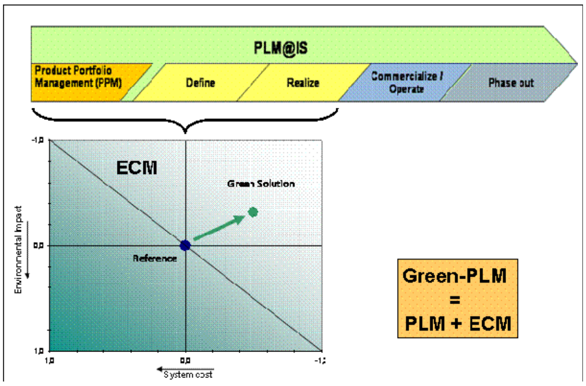


Fig. 1: Green-PLM = PLM + Eco Care Matrix (ECM)

The ECM describes both dimensions of economical performance (horizontal) and environmental impact (vertical). An existing technology / product / solution is set as a reference in the center of the ECM. The to be developed green solutions should be better in both eco-dimensions, i.e. eco-nomical and eco-logical. To describe the economical dimension it is favorable to use system costs e.g. CAPEX and OPEX. The ecological dimension is described by the LCA methodology described in chapter 2.1.

Siemens Industry Solutions is using the Green-PLM to generate the best green solutions for its customer base. A very positive site effect of the Green-PLM approach is that the engineers will create other ideas considering the environmental benefits of their design.

3 Industrial Case: Steel Plant

As a typical example for industrial processes different hot metal producing technologies were compared with ECM.

A LCA study aims to provide a holistic overview of the environmental impact of a technological process (see chapter 2.1 and ref. to [8]). Beginning with the mining of iron ore and coal up to the finished hot-metal product, it could be shown that direct reducing technologies like Corex® and Finex® ironmaking processes score much higher in an LCA rating when compared with the conventional blast furnace route (ref. to [9] and [10]).

Corex® and Finex® are innovative smelting-reduction processes in which non-coking coal is directly used as the energy source and reducing agent for the production of hot metal. But to what extent are they environmentally compatible and how can this be proved? Up until recently, this question has not been easy to answer. One approach had been to evaluate the results from mass balances or measurements, i.e., the quantity of potentially harmful substances released to the environment such as dust, SO_2, NO_x or CO_2. These were then compared with emissions from the blast furnace route, including the sintering and coking plants. With a LCA evaluation, as defined per ISO 14040 and 14044, a standardized method for generating a comprehensive picture of environmental impacts could have been applied.

3.1 Definition of environmental impact categories

In close cooperation with three universities – Technical University of Berlin (Germany), University of Mining and Metallurgy (Leoben, Austria) and Tekniske Universitet Copenhagen (Denmark) – a life-cycle assessment study was conducted in 2008 using the environmental software tool "GaBi" (ref. to [11]). Each step in the hot-metal production process, from the mining of iron ore and coal, the transportation to the plant site and the individual production steps to the final hot-metal product, were modelled and analyzed. All by-products and their subsequent utilization were also taken into account. Five key impact categories were identified in this study:

1. Acidification Potential (AP)
2. Abiotic Resource Depletion Potential (ADP)
3. Global Warming Potential (GWP)
4. Photochemical Ozone Creation Potential (POCP)
5. Eutrophication Potential (EP)

The **Acidification Potential** provides an overview of the acidic components that are released to the environment, for example, SO_2, NO_x, HCl, HF, H_2S and NH_3. The gaseous substances SO_2 and NO_x are transformed to sulfuric and nitric acid if they come into contact with water. Acid rain is a well-known consequence which causes damage to buildings, the biosphere and the soil. Forest dieback gained notoriety in the mid-1970s.

The **Abiotic Resource Depletion Potential** considers natural resources which are subdivided into "nonrenewable deposits" (e.g., iron ore or fossil fuels), "renewable funds within a human lifetime" (groundwater and some soils, etc.) and "continually renewed flows" (wind, river water and solar energy, etc.). Processes are more sustainable if they are based on the use of coal, which is abundantly available worldwide, instead of non-coking coal, where resources are clearly limited.

One of the most frequently discussed environmental topics today is **global warming**, which most experts believe is caused by an increase of so-called greenhouse gases (carbon dioxide, methane and CFC compounds, etc.) in the atmosphere. These gases as well as water vapor raise the atmospheric temperature by absorbing infrared radiation reflected from the surface of the earth.

Photochemical Ozone Creation Potential describes the formation of ozone (O_3) in the presence of NOx, hydrocarbons and sunlight (summer smog). Although the mechanisms behind this form of ozone creation are highly influenced by weather conditions, industry and traffic also play a major role.

Another important factor that has to be determined when assessing the environmental impact is the **Eutrophication Potential**. It determines the degree of over-fertilization, which can be aquatic or terrestrial. Needless to say, hot-metal production has not been a primary culprit in polluting the environment with nutrients, yet it is nevertheless a factor that has to be considered for a holistic overview of environmental impacts.

3.2 Evaluation of environmental impacts with LCA

The relative importance and magnitude of the above-described five impact categories were evaluated for the Corex®, Finex® and blast furnace iron making routes. This was performed applying two different normalization methods referred to as the CML (Institute for Environmental Sciences, Leiden, ref. to [12]) and EDIP methods (Environmental Development of Industrial Products, ref. to [13]). This approach allowed an enormous amount of complex and interrelated data to be illustrated in a single overview diagram. Specific customer-relevant parameters, such as the raw material properties, the related transportation aspects and the energy sources, have an influence on the overall picture. Different electricity mixes (country-specific ratio of hydroelectric-, nuclear-, wind- or coal-based power generation) were also taken into consideration.

Under European conditions, it could be shown that all three iron making production routes are comparable with respect to global warming (GWP). Corex® and Finex® have a better LCA rating for all other categories when compared to the blast furnace route. For Chinese steel producers, as well as for most developing countries, the LCA for the Corex® and Finex® processes provides a much better outcome than the conventional blast furnace route. This is also valid for global warming, which is roughly 30 percent less. This is due to the utilization of the export gas from the Corex® and Finex® plants for the generation of electricity, which substitutes coal. In fact, when considering the Acidification Potential (mainly SO_2 emissions), the inverted graph result indicates a "positive" impact on the environment.

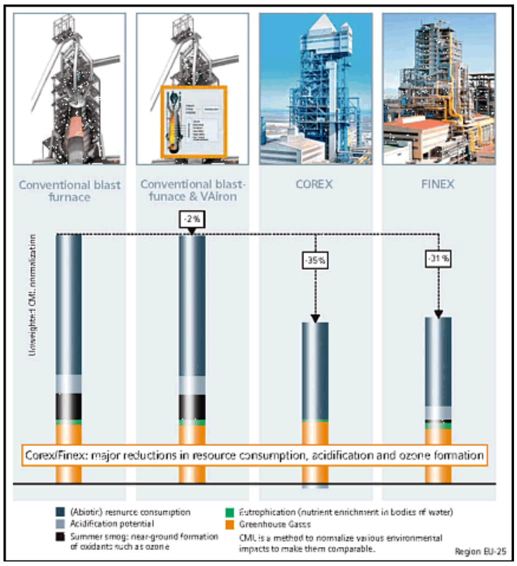
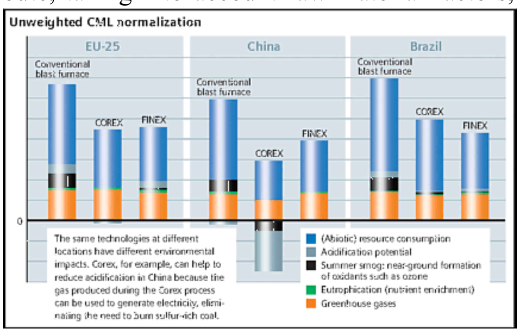


Fig. 2: Comparison of LCA results for different hot metal producing technologies (ref. to [10]).

The results of an independent life-cycle assessment of the most important hot-metal production processes, taking into account key environmental performance indicators, has shown that the Corex® and Finex® processes are environmentally more compatible than the conventional blast furnace production route, especially at sites where coal is used as an energy source to generate electricity. As a supplier of Corex®, Finex® and blast furnace technology, Siemens Industry Solutions can ideally support iron and steel producers in the selection of the optimum hot-metal route, taking into account raw material factors, local



site conditions, cost aspects and environmental requirements.

Fig. 3: Regional comparison of LCA results for different hot metal producing technologies (ref. to [10]).

3.3 ECM for different hot metal producing technologies

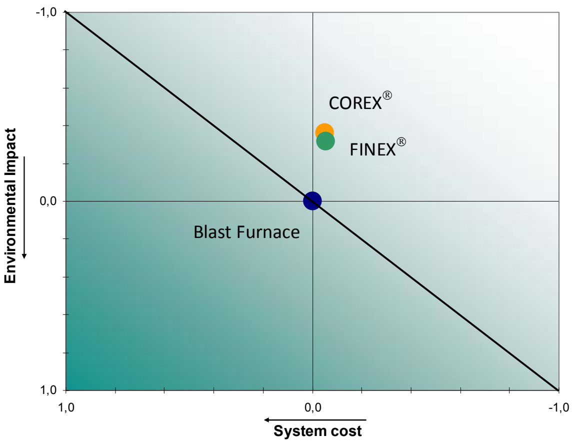


Fig. 4: Eco Care Matrix for different hot metal producing technologies (geographical reference: EU-25).

Figure 4 shows the ECM combining the LCA results with detailed cost analysis for the three hot metal producing technologies. Corex® and Finex® are Green solutions showing lower environmental impact and lower system costs than the blast furnace technology (reference).

4 Infrastructure Case: City Tolling

This second example section describes another application of ECM for eco-efficiency assessment of infrastructural processes. As an example different electronic tolling technologies in the application of city tolling systems were compared to each other in terms of ecology and economy.

4.1 Evaluation of environmental impacts with LCA

In order to assess environmental effects of a City tolling system it is assumed that a road pricing scheme is to be implemented in Copenhagen.

Economical effects of road pricing schemes have been derived from the revenue stream. Revenue is the income from road users' payments to the Road Pricing scheme minus the cost of establishing and maintaining the scheme.

Ecological effects of road pricing schemes have been calculated from pollution which will primarily be measured by airborne pollutants, (incl. CO_2 and particulate matter).

Traffic behaviour will be primarily measured by the ability for the city to manage traffic as intended and the general willingness to change behaviour by the population, the total distance driven, and the average velocity of the vehicles. For the modelling it is necessary to consider the area of Greater Copenhagen splitted into 835 zones shown in figure 5.

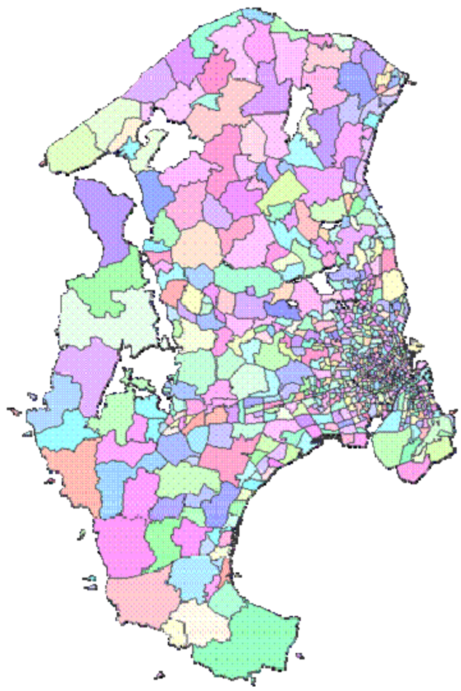


Fig. 5: Illustration of zones modelling the traffic demand from one zone to each other zone (Greater Copenhagen).

To find the most ecological and economical city tolling system for Copenhagen three different road pricing schemes were evaluated:

1. **Distance based road pricing** where the pricing is a function of the distance driven within a zone. In this case the Road Pricing scheme is based on GPS in possible combination with a secondary technology for enforcement such as camera or RFID.

2. **Area based road pricing** where there is a fixed price for entering a zone. The technology here can be GPS, RFID, camera or another stationary technology.

3. **Mixed distance & area based road pricing** where road pricing schemes 1 and 2 are mixed up specific for different vehicle types.

The baseline scenario that will be used when evaluating the above three road pricing schemes will be the initial situation of no city tolling in operation.

The Traffic Flow Model considers the traffic demand for each of the zones to all remaining zones differentiated in terms of different vehicle type classes (passenger cars gasoline/ diesel, heavy/ light duty trucks) and in different time slices during a typical working day.

The environmental evaluation is based on the traffic flow model, evaluating the potential impacts on both the environment and on human health. The whole fuel cycle is included (i.e. primary production, transportation, refining and vehicle operation) but the vehicle cycle (production and disposal of vehicles) is omitted. The evaluation focuses primarily on quantifying the extent and impacts of life cycle air-borne emissions arising from the fuel cycle. The reason for this focus is due in part to the importance of air emissions in the context of road transport, and also due to the time and resource limitations of the study. The air emissions assessed include the three main greenhouse gases: carbon dioxide, nitrous oxide and methane. In addition, the regulated emissions associated with road transport are assessed (carbon monoxide, oxides of nitrogen, hydrocarbons and particulates).

For the assessment of impacts to the environment, general LCA impact assessment methodologies are applied (see chapter 2.1). When modelling the potential exposure of humans it will be attempted to apply a generic fate and exposure model with spatial differentiation allowing taking into account a low emission height and a high population density measured by the number of inhabitants per area.

Figure 6 shows the global warming potential compared between the three road pricing schemes for Copenhagen.

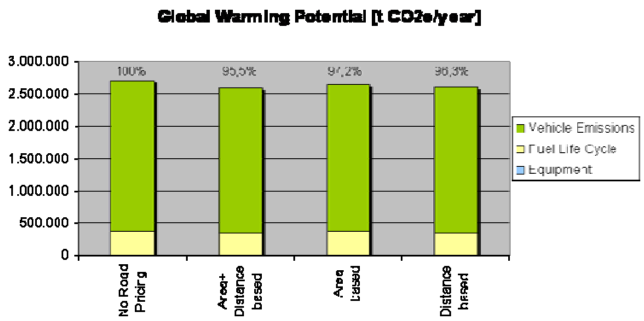


Fig. 6: Environmental impact for different road pricing schemes compared to baseline.

4.2 ECM for different road pricing schemes

System costs are calculated based on the equipment necessary in the different road pricing schemes. The amount of equipment necessary will be estimated on the basis of infrastructure, level of enforcement and other equipment needed. Economical performance of a city tolling solutions can be calculated in terms of amortization time (months).

Figure 7 shows the Eco Care Matrix for three different road pricing schemes for the city and surrounding area of Copenhagen. Additionally it was calculated the scenario of Copenhagen assuming the same congestion charge approach as in London ("London Scenario").

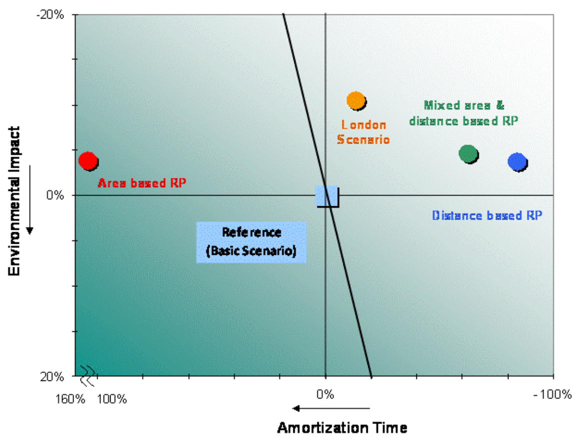


Fig. 7: ECM for different road pricing schemes for Copenhagen.

All three road pricing schemes show a lower environmental impact compared to the baseline (no road pricing system). The area based road pricing scheme shows a very long amortization time due to the high investment costs needed. The other road pricing schemes (mixed area & distance based, distance based road pricing) show shorter amortization time. The London city approach shows a better environmental performance but a less attractive economic evaluation. This analysis shows the advantage of the ECM approach to find the right road pricing scheme. Of course for investment decisions much more detailed calculations have to be conducted.

4.3 Immissions derived from emissions

In addition to the above discussed analysis of environmental and economical impacts of a city tolling solution this section describes the approach of a dispersion analysis deriving immission related data based on local emissions. Vehicle emissions of airborne pollutants are normally dispersed in the atmosphere depending from local metereological weather conditions (wind speed & direction, rainfall, change in atmospheric pressure, temperature, etc.). Key issue for performing a dispersion analysis is knowledge about the 3-dimensional shape of buildings forming the geometric constraints of roads.

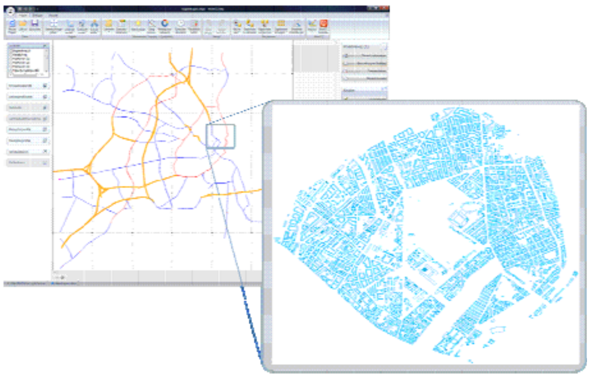


Fig. 8: Combination of road network with 3-dimensional building data

Figure 8 shows the combination of 2-dimensional road network data with 3-dimensional shape information regarding road surrounding buildings. Depending on the heights and shape of buildings the airborne pollutants will be dispersed according to the specific pattern of airflow caused by wind.

The influence of building shape and heights on dispersion of airborne pollutants is illustrated in figure 9 displaying the concentration of PM20 in µg/m³ for a given building group near to a road.

Fig. 9: Dispersion without considering building heights

Beside the ECM approach the analysis of the immissions is crucial to the decision of the appropriate road pricing scheme in Copenhagen.

5 Conclusion

To meet the worldwide climate challenge the industrial products and solutions have to become much more environmental sound. The Siemens-Division Industry Solutions has extended its existing PLM to a "Green-PLM" to trigger the design and engineering of green products / solutions.

The key element in the Green-PLM is the "eco care matrix" (ECM) which defines environmental sound industrial products / solutions with advantages in both "eco" dimensions (eco-nomical + eco-logical). Two case studies are illustrated, i.e. hot metal producing technologies (industrial case) and electronic city tolling systems (infrastructure case).

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