321: Agricultural Waste Materials as Thermal Insulation for Dwellings in Thailand: Preliminary Results

Satta Panyakaew [1]*, Steve Fotios [1]

School of Architecture, the University of Sheffield, Sheffield, UK[1]*
s.panyakaew@sheffield.ac.uk

Abstract

There is a trend in Thailand for the design of dwellings to move away from the traditional, climate responsive architecture towards a style influenced by western architecture. This trend means that buildings are less able to control the internal environment to comfortable conditions without mechanical air conditioning. One technique for reducing the scale of air conditioning is to apply thermal insulation in walls and roofs. This project is exploring the potential for using agricultural waste as the material for this thermal insulation, a solution which offers a reduction in resource use in addition to reducing energy consumed by air conditioning, similar to the use in the UK of sheep fleece as a thermal insulation to reduce heat loss. The criteria evaluated include the availability of agricultural waste materials, their physical properties when transformed into a useable product, methods of production and their environmental impacts. There are several possible materials including bagasse (the waste from sugarcane production), rice hulls, coconut husk, corn stalk, durian peel, and palm oil leaves. The results from preliminary evaluations have identified the three materials offering greatest potential are bagasse, rice hulls and coconut coir.

Keywords: agricultural waste, thermal insulation

1. Introduction

Thailand is located in a monsoon region with a mean temperature of 27.1°C and mean relative humidity of 71%. [1] In response to this hot humid weather, Thai dwellings need high ventilation rates to combat excessive heat and moisture to provide comfortable environments. Traditional Thai architecture is designed using passive approaches to maximize natural ventilation whereas contemporary architecture typically resorts to mechanical systems, particularly air-conditioning, to lower the temperature.

In vernacular Thai architecture (Fig. 1), dwellings were cooled through a combination of solar shading and high levels of natural ventilation. The interior spaces were open plan, avoiding internal obstruction to air flow; they were elevated above the ground, allowing air flow underneath to cool the floor. The walls and windows were shaded by the roof overhang. The roof had a steep pitch to provide space and height for stack ventilation – buoyancy lifts hot air up and out of the house through vents in the gable. The steep pitch also encourages rapid drainage of rainwater to reduce absorption within the thatch roof.

In addition, these traditional Thai houses were constructed by using agro-materials (plant-based materials) such as timber, thatch and leaves that have a low thermal conductivity [2]. Therefore, they were naturally comfortable.

Today, these vernacular concepts have been lost. There is a trend for Western style housing with no consideration for climate (Fig. 2). The cost of building a classical Thai house is now expensive and unaffordable for ordinary people. Most of these dwellings are air-conditioned to keep people in comfortable conditions, i.e. cool and dry, and this consumes a lot of energy.

Fig. 1 Traditional Thai house

Fig. 2 Western Style Thai house

Bangkok is densely populated and the air is very polluted. In this environment it is difficult to the design buildings which can take advantage of natural ventilation. Air-conditioning systems are therefore common in urban houses. In order to use these systems efficiently and economically, houses need building envelopes that can minimise the ingress of heat and moisture from the exterior environment. For this reason, thermal insulation of the external walls and roof is now essential for air-conditioned houses in Thailand.

Common choices of thermal insulation are fibreglass, rock wool and mineral wool. There are environmental hazards associated with these materials. The small particles from fibreglass and glass wool insulation can cause health hazard and respiratory or skin irritant [3]. Breathing fibres may irritate the airways resulting in coughing and throat irritation. The Seventh Annual Report on Carcinogens lists glass fibres of respirable size as a substance "reasonably anticipated to cause cancer in humans" [4].

Most thermal insulation batts contain formaldehyde resin that can affect sensitive people and may cause asthma [5]. Cellulose insulation with toxic, fire-retarding chemicals like boric acid, have been identified as having the potential for significant health effects [6].

Thermal insulation materials are chosen for their physical properties such as low thermal conductivity, moisture protection, and mould and fire resistance. The most widely used categories of insulating materials are inorganic fibrous and organic foamy materials - expanded and extruded polystyrene and, to a smaller extent, polyurethane [7]. However, concerns for sustainability demand that environmental and health impacts should be considered in addition to these physical properties.

Considering the fact that the current popular insulation materials have negative side effects from the production stage until the end of their useful lifetime [8], it is necessary to search for alternative insulation materials which can satisfy the new standards.

The aim of this research is to investigate the potential of alternative materials, agricultural waste, for use as thermal insulation in Thai dwellings.

2. Potential for Using Waste Materials as Thermal Insulation

Thailand is an agricultural country: approximately 21 million hectares or 41% of the total area is used for agricultural production [9]. There is considerable waste produced by the agricultural industry. Waste generated by harvest and post harvest operations from agricultural industries are usually burned or dumped into the landfills. The disposal of this waste becomes a major problem. In addition, leaking and improper storage of agricultural waste can also give rise to emissions of ammonia and methane which can cause acidification and contribute to greenhouse gas emissions [10]. One solution to the problem of waste management is to utilise them as building materials. Agricultural wastes, such as rice hulls, sugarcane stalk, coconut husk, corn cob or stalk, oil palm shell or leaves, or straw from cereal crops, have high degrees of fibrous content (ligno-cellulosic compounds), which serve as the main ingredient for composite materials, making them suitable for manufacturing boards or panels [11]. The potential of these materials for thermal insulation is discussed with consideration to the following issues.

- Availability of the agricultural waste material: how much is generated within the agricultural industry.
- Physical properties: thermal and other properties of the insulation products made from the agricultural waste.
- Environmental and health impacts: the impacts from the processes of production of waste materials into insulation board.
- Applications: transformation into useable construction materials.

2.1 Rice Hulls

Throughout the world, more than 100 million tonnes of rice hulls are generated each year [12]. In 2004, the annual Thailand supply of rice hulls exceeded five million tonnes [13]. Since most mills store rough rice and process it on a daily basis, fresh dry hulls are available all year round.

Rice hulls are solid waste materials with potential for use as building insulation [14]. The thermal conductivity of rice hull has been measured using equipment built and operated in accordance with ASTM methods and this suggests that thermal conductivities of rice hulls are between 0.046 – 0.057 W/mK [15]. These values compare well with the thermal conductivity of excellent typical insulating materials. Table 1 shows further physical properties of Rice Hull boards – these are similar to those for a conventional thermal insulation material (Table 2).

Table 1: Physical properties of Rice Hull boards [15]

Test (ASTM)	Result	
Critical Radiant Flux	0.29 W/cm^2	Pass
Smouldering Combustion	0.04 wt %	Pass
Moisture Vapour Sorption	3.23 wt %	Pass
Corrosiveness	No holes	Pass
Odour	No odour	Pass
Flame Spread	10	Class A
Smoke Developed	50	Class A

Table 2: Physical properties of cellulose insulation [16]

Test (ASTM)	Result	
Critical Radiant Flux	>0.12W/cm^2	Pass
Smouldering Combustion	<15 wt%	Pass
Moisture Vapour Sorption	<15 wt %	Pass
Corrosiveness	None	Pass
Odour	Acceptable	Pass
Flame Spread	<25	Class A
Smoke Developed	<50	Class A

One application of rice hulls is to convert them into composite boards. This board can be formed without use of urea formaldehyde resin or any type of phenol formaldehyde resin which is used in most fibreglass insulation, and do not use chlorine-base chemicals such as phosgene, propylene chlorohydrins or any ozone - depleting chlorofluorocarbons [17].

2.2 Coconut Husk

Coconuts grow abundantly in coastal areas of tropical countries and a wide variety of products are used in food and non-food products. The coconut husk is available in large quantities as residue from coconut production. World production of coconuts is around 40 to 50 million tonnes annually, producing around 15 to 20 million tonnes of husks [18]. Coconut cultivation can is found in most of Southeast Asia. Thailand is ranked sixth in world coconut production, with 1.5 million tonnes produced in 2003 [18].

Coconut husk has been used as a raw material for making building insulation boards [19, 20] using the hot pressing method of a manufacture process that uses urea formaldehyde resin. Measurements in accordance with BS874-2 [20] show that the boards have low thermal conductivity, varying between 0.054 and 0.143 W/mK.

Whilst boards made from coconut husk are a practical option for a thermal insulation material, the production process uses synthetic resin and emits toxic components such as formaldehydes, and thus they have a disadvantage in terms of environmental and sustainable issues. However, it may be possible to use coconut husk lignin at elevated temperatures as an intrinsic resin in board production and this would eliminate the need for chemical binders and additives. [21]

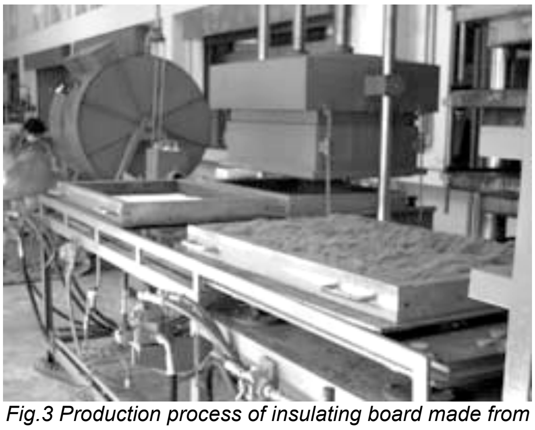

Fig.3 Production process of insulating board made from coconut husk [22]

2.3 Bagasse

Sugarcane is a major crop in many tropical countries following the increasing demands for sugar in the last century. Today, Thailand has the fourth largest producer of sugarcane, producing around 58 million tonnes each year. [23] Besides the main product, sugar juice, several by-products are available in the sugarcane extraction process, the most important of which is considered to be bagasse, and Thailand produces around 14-17 million tones of bagasse each year [24].

Sugar is produced by crushing sugar cane in mills - the cane stalk is broken into small pieces and the juice is squeezed out. The juice is collected and processed for sugar. Bagasse is the crushed and squeezed cane stalk, essentially a waste product that causes mills to incur additional disposal costs [25]. The utilisation of bagasse as a raw material for other uses improves the environmental performance of the sugar industry.

Bagasse can be made into soft boards, medium density fibreboards or particleboards, as well as high density hardboards [26, 27]. It can be upgraded by bonding with phenolic resin, producing boards and panels that are strong, durable, heat and moisture resistant, light weight, and easily transportable [27]. Bagasse thermal insulation has been produced, this having thermal conductivity in the range 0.046 – 0.051 W/mK [26], and has been trialled as roof insulation in Jamaica, Ghana and the Philippines [27].

2.4 Corn Cob

The world production of corn was over 600 million tonnes in 2003, slightly more than rice or wheat. While the United State produces almost half of the world supply, other major producers are China, Brazil, Mexico, Indonesia and India. Thailand produced around 4 million tonnes of corn in 2005 [28]. Corn stalks and cobs can be made into particleboards and fibre boards [29]. They have been tested for use as raw materials for low density boards made using the hot press method and using urea formaldehyde resin. It was found that the boards exhibited a high mechanical strength and have a thermal conductivity of 0.096 W/mK. [19]

2.5 Durian Peel

Durian is widely known in Southeast Asia as the King of Fruits. [30] All durian species are mainly produced in Southeast Asia countries. Thailand is currently one of the major exporters of durians, and in 1999 grew and exported more durian than any other country - about 780,000 tonnes [31].

Durian fruit is used to flavour a wide variety of sweet foodstuffs. In Thailand, blocks of durian paste are sold in the markets; unripe durians may be cooked as vegetable, and the durian seeds, which are the size of chestnuts, can be eaten whether they are boiled, roasted or fried in coconut oil. The husk (durian peel), waste product from durian industry, can be used as fuel or fertilizer for trees.

The thermal conductivities of durian peel particleboards were determined by using hot flux method in accordance with BS 874-2 with boards of size 300 x 300mm. The test results show that durian peel particleboards have thermal conductivity in the range 0.064 – 0.159 W/mK [20].

2.6 Oil Palm Leaves

The oil palm was brought to Southeast Asia in the 19th century but commercial planting only started in the early 20th century. Now, Southeast Asia produces more palm oil than West Africa. Malaysia and Indonesia are the two leading producers, with about 95% of the total production in Asia. Thailand is the fourth largest producer of palm oil – about 5 million tonnes in 2005 [32].

Oil palm leaves are a by-product from the palm oil production process. In 2005 around 6 million tonnes of oil palm leaves were generated in Thailand. Since oil palm leaves consist of large amounts of ligno-cellulose components and have high fibre yield, they are now used to manufacture mattresses, composite panels and particleboards. A thermal insulation board of average thermal conductivity of 0.127 W/mK has been made by mixing oil palm leaves with granular wood glue in the ratio (glue:leaf) 1:4 by weight . [33]

Furthermore, oil palm leaves with high lignin component can be used to produce a binder-free fibreboard by using the steam-explosion method. These boards at density of 1200 kg/m^3 met the requirement of S-20 grade of JIS A 5905 – 1994 (fibreboard). [34]

3. Discussion

Three key qualities of a thermal insulation material derived from agricultural waste are resource availability, physical properties and environmental impacts. These qualities are compared below.

3.1 Resource Availability

As shown in Figure 4, bagasse is the most abundant agricultural waste material in Thailand. Up to 5 million tonnes of oil palm leaves and rice hulls are available each year, five times the available supply of coconut husk, corn cob and durian peel [13, 24, 31].

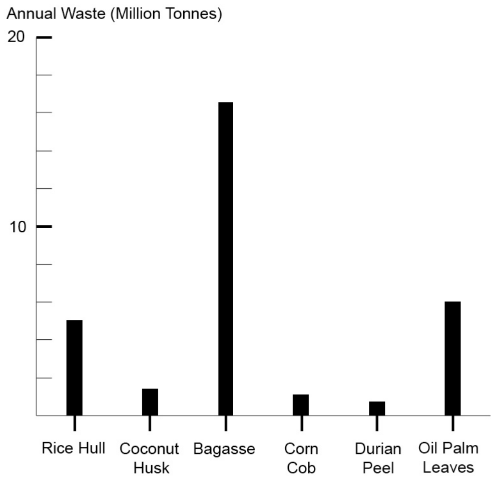

Fig. 4 Annual production of agricultural waste in Thailand [13, 24, 31].

3.2 Physical Properties

Critical physical properties include resistance to fire, mould growth, insect damage and bio-degradation in addition to thermal properties. Good thermal insulation with low material thickness demands a material that has a low thermal conductivity. Figure 5 shows that rice hulls, bagasse and coconut coir have lower thermal conductivities than corn stalk, durian peel and oil palm leaves.

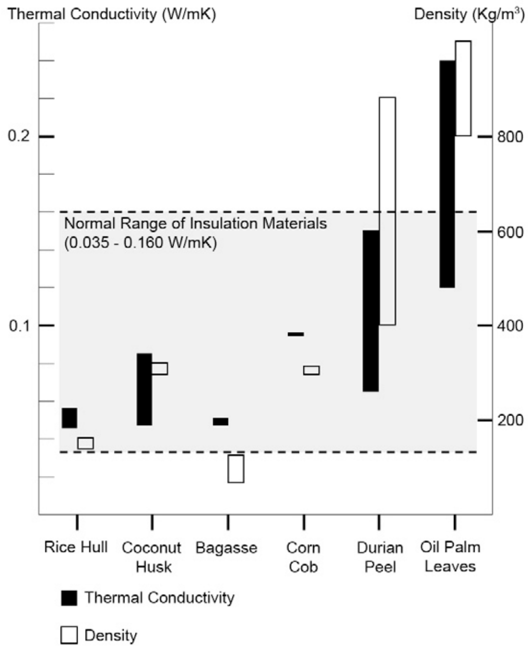

Fig. 5 Comparison of thermal conductivities and densities of insulation board made from agricultural waste materials [15, 19, 20, 26, 33].

Insulation boards made from rice hulls and durian peel have lower moisture content than others [15, 20]. Bagasse and Oil palm leaves are found that when they are bonding with phenol formaldehyde resin to produce boards or panels, water absorption and moisture content will decrease [27, 35] The phenolic binder can expel the moisture and provides strength and rigidity in both materials when it is heated to 140^{o}C in less than 30 seconds during a hot pressing process in the board production. [27, 35] Coconut insulation board contains high moisture content which affects the probability of mould growth inside the material structure. Therefore, the applications of coconut coir insulation in the building envelope can be more effective when they are combined with moisture protection materials.

Data on fire resistance testing has been found only for rice hulls. The test result showed that the high percentage of silica within rice hulls can prevent the regular burning and on flame or smoulder retardants required for boards production [15].

3.3 Environmental and Health Impacts

The production of boards made from agricultural waste materials normally needs chemical binders in the production process, e.g. urea formaldehyde,

phenol formaldehyde or isocyanate. The emission of these chemical binders can affect human health and indoor air quality [5].
Rice hulls and bagasse can be made into hard (high density) boards without the use of chemical binders. Coconut husk can be made into thermal insulation board without binders. Corn stalk and durian peel require chemical binders in order to produce boards or panels.

4. Conclusion

The three agricultural waste materials offering greatest potential for manufacturing into thermal insulation products are bagasse, rice hulls and coconut coir.

- Bagasse is the most abundant material. It has low thermal conductivity, and it is environmental friendly as it can be made into boards or panels without using any chemical resins.
- Rice Hulls insulation boards have the lowest thermal conductivity. When produced into insulation boards, they have lower moisture content and higher fire protection compared to other agricultural waste materials. Rice is cultivated in all parts of Thailand and may therefore lead to low embodied energy.
- Coconut coir has low thermal conductivity and the coconut board insulation manufacturing process is benign as coconut coir board does not require chemical binders. However, it has high moisture content and therefore the applications of coconut coir insulation in the building envelope require moisture protection.

Whilst these materials prove a good resource for thermal insulation, having low thermal conductivity and low embodied energy, consideration has to be given to the flammability and problems of insect attack and fungal growth over long time periods need to be further investigated.

5. Further Work

The next stages of work consider applications as a thermal insulation material using life cycle analysis (LCA) to evaluate environmental and health impacts in the context of Thailand.
The LCA of using waste materials will be a gate-to-gate analysis, i.e. commencing with the waste product of food production as it leaves the gate of the food production factory to the exit gate of the insulation manufacturing process. Whilst this assumes the waste material is essentially free, the analysis will consider the harmful effects of residual agricultural chemicals such as insecticides and fertilizers.
This evaluation will use the IMPACT 2002+ method for impact assessment and Simapro 7.0 as the LCA software tool. IMPACT 2002+ is a combined midpoint [36] and damage approach [37], linking the various components of the life cycle inventory using 14 midpoint categories to four damage categories. *Midpoint* defines impacts that are evaluated at an early stage in the cause-effect chain according to themes such as climate change or global warming; the *damage* impact is that at the end of cause-effect chain: i.e. human health, the ecosystem, and resources. This method has been developed, especially for the assessment of human toxicity (calculated for carcinogens) and indoor air quality. Therefore, it is suitable to assess the impact of insulation materials when applied to interior space.
Simapro 7.0 is a software tool that contains several impact assessment methods and inventory databases, which can be edited and expanded without limitation. It can compare and analyse the complex products and present the result in a graphic format that is easy for users to understand.
The final results will provide information for comparing thermal insulation made from agricultural wastes and conventional materials. Whilst this project focuses on Thailand, the findings are of international relevance.

7. References

1. Climatology Division of Thai Meteorological Department, (1981-2007). *Thailand Climate Data*, Computer Section, Editor.
2. National Association of Forest Industries, (2004).*Timber Species and Properties*, in *Timber Manual Datafile P1*.
3. Occupational Safety and Health Administration, (2003). *Synthetic Mineral Fibers: Health Hazards*. United State Department of Labor.
4. Infante PF, et al., (1994). *Fibrous glass and cancer.* American Journal of Industrial Medicine, 26: p. 559-584.
5. U.S. Environmental Protection Agency, (2000). *Health and Environmental Effect Profile for Formaldehyde*, Office of Health and Environment Assessment, Office of Research and Development: Cincinnati.
6. The U.S. Occupational Safety and Health Administration (OSHA), 1999. *the Health and Safety Partnership Program*, the North American Insulation Manufacturers Association.
7. Papadopoulos, A.M. and E. Giama, (2006). *Environmental performance evaluation of thermal insulation materials and its impact on the building.* Building and Environment.
8. Papadopoulos, A.M., (2005). *State of art in thermal insulation materials and aims for future developments.* Energy and Building, 37: p. 77-86.
9. Office of Agricultural Economics, (2004). *Agricultural statistics of Thailand, Ministry of Agriculture and Cooperatives*: Bangkok, Thailand.
10. European Environmental Agency, (2006). *Agricultural Waste*, European Topic Centre on Resource and Waste Management.
11. Rowell, R.M., R.A. Young, and J. Rowell, (1996). *Paper and Composites from Agro-based Resources*, New York: CRC Press.
12. FAO Statistics Division, (2004). *World Production of Rice, Paddy*, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.
13. Methacanon, P., (2006). *Raw Materials available in Thailand*. in *InnoBioPlast*. Bangkok, Thailand: National Innovation Agency.

14. Olivier, P.A., (2003). *The Rice Hull House*, in *Engineering, Seperation, & Recycling*: Washington, LA.
15. Yarbrough, D.W., et al., (2005) *Apparent Thermal Conductivity Data and Related Information for Rice Hulls and Crushed Pecan Shells.* Thermal Conductivity, 27: p. 222-230.
16. AFT (Advanced Fiber Technology), (2003). *Loose-Fill Cellulose Insulation Specification.*
17. AMPAN (Australian-Made Panel), (2005). *AMPAN Panel-Board: Rice Straw Based Fibre Board*, Australian Environmental Labelling Association Inc (AELA).
18. FAO Statistics Division, (2003). *World production of coconuts*, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.
19. Sampathrajan, A., et al., (1992). *Mechanical and Thermal Properties of Particle Boards Made from Farm Residues.* Bioresource Technology, 40: p. 249-251.
20. Khedari, J., (2003). *New insulating particleboards from durian peel and coconut coir.* Building and Environment, 38: p. 435-441.
21. Jan E.G. van Dam, et al., (2004). *Process for production of high density/high performance binder less boards from whole coconut husk.* Industrial Crop and Products, 19: p. 207-216.
22. The Greenery Product, (2006). *Biobase Composite - Free of Formaldehyde*: Thailand.
23. FAO Statistics Division, (2005). *World production of sugarcane*, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.
24. Sriroth, K., (2002). *Outlook of Biomass Utilization as Biofuel in Thailand*, Kasetsart Agricultural and Agro-Industrial Product Improvement Institute (KAPI): Bangkok.
25. Chiparus, O.I., (2004). *Bagasse Fibre for Production of Nonwoven Materials*, in *The school of Human Ecology*, Louisiana State University and Agricultural and Mechanical College: Louisiana.
26. Krishpersad, M., et al., (2006). *Biodegradable Fibrous Thermal Insulation.* Journal of the Brazilian Society of Mechanical Sciences and Engineering, 28: p. 45-47.
27. Arthur M. Usmani, et al., (1980). *Alternative Low Cost Roofing Material Candidates Based On Bagasse Filled Composites.* Journal of Elastomers and Plastics, 12:18.
28. FAO Statistics Division, (2005). *World production of Maize*, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.
29. Chow, P., (1974). *Dry formed composite board form selected agricultural residues*, in *World Consulation on Wood Based Panels*, Food and Ahriculture Organiztion of the United Nations.: New Delhi, India.
30. Heaton, D.D., (2006). *A Consumers Guide on World Fruit*, BookSurge Publishing. p. 54-56.
31. Department of Alternative Energy Development and Efficiency, (2000). *Potential of Biomass Residue Availability*, Ministry of Energy: Bangkok, Thailand.
32. FAO Statistics Division, (2005). *World production of oil palm*, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.
33. R.S. Al-Juruf, F.A. Ahmed, and I.A. Alam, (1988). *Development of Heat Insulating Materials Using Date Palm Leaves.* Journal of Thermal Insulation, 11: p. 158-164.
34. Leamsak, N. and M. Okuma, (2000). *Development of boards made from oil palm frond II: properties of binderless boards from steam-exploded fiber of oil palm frond.* Journal of Wood Science, 46: p. 322-326.
35. Faleh A. and Al-Sulaiman, (2003). *Date palm fibre reinforced composite as a new insulating material.* Internaltional Journal of Energy Research, 27(14): p. 1293-1297.
36. Guinee, J., et al., (2002). *Life cycle Assessment: An Operational Guide to the ISO Standards*, Dordrecht (NL): Kluwer Acadamic Publishers.
37. Goedkoop, M. and R. Spriensma, (2000). *The Eco-indicator 99: A Damage Oreinted Method for Life Cycle Assessment, Methodology Report*, Pre Consultants, Editor: Amerfoort (NL).