Estimation of construction waste generation and management in Thailand

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ABSTRACT

This study examines construction waste generation and management in Thailand. It is estimated that between 2002 and 2005, an average of 1.1 million tons of construction waste was generated per year in Thailand. This constitutes about 7.7% of the total amount of waste disposed in both landfills and open dumps annually during the same period. Although construction waste constitutes a major source of waste in terms of volume and weight, its management and recycling are yet to be effectively practiced in Thailand. Recently, the management of construction waste is being given attention due to its rapidly increasing unregulated dumping in undesignated areas, and recycling is being promoted as a method of managing this waste. If effectively implemented, its potential economic and social benefits are immense. It was estimated that between 70 and 4,000 jobs would have been created between 2002 and 2005, if all construction wastes in Thailand had been recycled. Additionally it would have contributed an average savings of about $3.0 \times 10^6$ dollars per year in the final energy consumed by the construction sector of the nation within the same period based on the recycling scenario analyzed. The current national integrated waste management plan could enhance the effective recycling of construction and demolition waste in Thailand when enforced. It is recommended that an inventory of all construction waste generated in the country be carried out in order to assess the feasibility of large scale recycling of construction and demolition waste.

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1. Introduction

Construction and demolition (C&D) waste is the waste produced during new construction, renovation, and demolition of buildings and structures. It is most often disposed of in landfills; however, recent recognition of the potential for the diversion of waste components from landfills has led to C&D waste becoming a target of interest for recycling. Several researchers have attempted to estimate the amount of construction and demolition waste in various countries. About one-third of the volume of materials in landfills in the US is C&D waste (Chun-Li et al., 1994; Kibert, 2000). Data available for some European countries also indicate that the amount of C&D waste varies from country to country depending on how it is defined. In 1996, the amount of C&D waste in Austria, Denmark, Germany and The Netherlands were about 300, over 500, about 2600 and about 900 kg/cap, respectively (Brodersen et al., 2002). It has also been reported that C&D waste took up about 65% of Hong Kong's landfill space at its peak in 1994–1995 (Stokoe et al., 1999).

Construction waste is the waste generated from various activities such as clearing of sites, and the building of new structures or infrastructure (Fatta et al., 2003). A lot of research has been carried out on its minimization, management and potential utilization (Al-Mutairi and Haque, 2003; Bossink and Brouwers, 1996; Donovan, 1991; Lauritzen, 1994; Peng et al., 1997; Poon et al., 2002; Trankler et al., 1996). In the US, estimates by the Environmental Protection Agency (USEPA) indicated that approximately 136 million tons of building-related construction waste was generated in 1996 (US Environmental Protection Agency, 1998). Another study stated that construction waste constitutes about 29% of the solid-waste stream in the USA (Rogoff and Williams, 1994). In Canada, 35% of the space in landfills is taken up with construction waste, and over 50% of waste in a typical UK landfill could be construction waste (Ferguson et al., 1995). Similarly, studies of Australian landfills have revealed that construction activity generated about 20–30% of all deposited wastes (Craven et al., 1994). In most of these countries, increasing attention is being given to the diversion of as much construction waste from landfills as possible through waste reduction, recovery, reuse and recycling.

Thailand is a country experiencing economic growth (World Bank Group, 2007). Associated with this, it has also been experiencing rapid urbanization, with the projected proportion of the total population living in urban areas growing from 21.5% in 1990 to 24.3% by 2010, and expected to continue increasing (United Nations Environment Program, 2001; United Nations University, 1996; US Energy Information Administration, 2004). The rapid urbanization of Thailand has generated an increased demand for housing and infrastructure which in turn generates huge quantities of construction waste. In many countries including Thailand, the
increasing unregulated dumping of construction waste and the scarcity of landfill space are becoming very serious issues. The management of construction waste is therefore a major priority, especially in Bangkok and the Northern provinces of Thailand where the population is much denser and the rate of building construction is higher than in other parts of the country as reflected by the number of new construction permits per year (Fig. 1) (National Statistics Organization of Thailand, 2007).

However, very little is known about the volume of construction waste generated in Thailand and its management. Therefore, the principal objective of this paper is to bridge this information gap by estimating the quantities of construction waste generated in Thailand from 2002–2005 as an incentive for: (a) the development of an integrated waste management system, and (b) the implementation of policies for managing construction waste in Thailand. The current status of construction waste management in Thailand is discussed. Key issues related to the feasibility and benefits of recycling construction waste in Thailand are also highlighted.

2. Construction waste management in Thailand: current practice and problems

In Thailand, construction waste is classified as part of municipal solid waste (MSW). It is manually collected and dropped through a temporarily erected refuse chute to the ground floor. It is then cleared out of the work site by the main contractor or by a subcontractor. A survey of 32 construction sites in Bangkok by Chanchorn (2002) revealed that about 69% of construction companies usually manage the disposal of these wastes themselves, while 31% contract the disposal to subcontractors or other individuals. Also, available information indicates that the majority of construction waste is disposed of either in uncontrolled sites or in other inappropriate sites (Ashford et al., 2000; Padungsirikul, 2003). Therefore, it is important to formulate laws and policies to motivate these companies to record and report the volume of construction waste they generate as well as the method(s) of treatment and disposal.

Usually, a material like wood is reused by contractors within the project as many times as possible to avoid the cost of collection and disposal and the extra cost of virgin material. Scrap dealers usually collect scrap metals (mostly off-cuts of metal sheets and bars), as well as other salvageable materials generated. These are resold to secondhand buyers or, if metals, to metal smelting companies. Although the collection and sale of these materials by collectors is a positive application of reuse and recycling, it is not a system that functions at an efficient level (Esin and Cosgun, 2005). As is the fate of most MSW components, some construction wastes end up in landfills, while the majority is disposed of either in uncontrolled sites or in other inappropriate sites (Ashford et al., 2000; Padungsirikul, 2003). According to a survey of solid waste disposal systems in Thailand, in 2004, 77.6% of the 425 disposal sites in the country were open dumps (Table 1), the rest being landfills (Chiemchaisri et al., 2006).

It was estimated that in 2000, 16–34% of collected MSW in Thailand had recyclable materials but only 7% (or 2,360 tons/day) was actually recycled (Padungsirikul, 2003). This is very low when compared with the recycling rates for C&D waste of other countries. In Denmark the percentage of recycling is more than 80%. Germany and The Netherlands, Finland, Ireland and Italy recycle 30–50%, while the recycling percentage in Luxembourg is 10% (Brodersen et al., 2002). Even building rubble (including concrete, brick, tile and asphalt), which is usually disposed of in open dumps in Thailand, can be recycled. In Australia, building rubble is by far the most recycled material. Calculations based on data from the Australian Government Productivity Commission (2006) also showed that in 2002–2003, approximately 50% of all recycled waste in Australia was C&D waste. There are many available technologies for recycling construction waste (Tam and Tam, 2006a). These could prolong the life of landfill sites, minimize transport needs and reduce the primary resource requirements (minerals and energy). Although there are many material-recycling schemes recommended by the government of Thailand, actual implementation of waste recycling is limited to a few components of MSW such as glass, plastic, paper and metals, which do not necessarily originate from construction activities.

The problem of construction waste management in Thailand is similar to that of Hong Kong in a number of aspects, namely; (1) insufficient budgetary allocation for MSW management and also, ineffective collection of service fee; (2) no active planning on establishing common disposal facility among adjacent communities; (3) no definite regulation and guidelines for construction waste management hierarchy starting from source separation, collection, transportation, disposal and monitoring; (4) lack of skilled personnel in operating an efficient waste collection and disposal practice; (5) absence of waste recycling programs in most communities; (6) associated existing legislation does not adequately facilitate the construction waste management in an effective direction; (7) lack of public co-operation and participation; and (8) lack of government legal enforcement, amongst others (Shen and Tam, 2002). It is noted that although some of these problems are similar in a number of areas, there could be quite a lot differences concerning possible management measures (e.g., distances, availability of skilled personnel, technologies etc.). Nevertheless, the availability of adequate information on certain parameters such as the volume

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**Fig. 1.** Distribution of new construction permits by region, 2002–2005.
3. Construction waste generation in Thailand

Construction waste is generated from various activities such as clearing of sites, and the building of new structures or infrastructure (Fatta et al., 2003). Construction waste is generally considered as an integral part of MSW in Thailand. MSW management has been recognized as a huge problem, and its quantities and characteristics have been documented. The total MSW generation in Thailand increased from 11.2 million tons in 1993 to 14.3 million tons in 2002. Also, the average per capita generation rate increased from 0.53 kg/cap/day in 1993 to 0.62 kg/cap/day in 2002. This indicates that the quantity of the generated MSW in Thailand and the per capita generation rate are both increasing with time, pointing to the need for a sustainable approach to disposal and management (Chiemchaisri et al., 2006). In 2003 the total amount of MSW generated in Thailand was approximately 40,165 tons/day (Table 2).

Table 2: Municipal solid waste generation in Thailand (kg/cap/day)

<table>
<thead>
<tr>
<th>Area</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Bangkok Metropolitan</td>
<td>8,990</td>
<td>9,131</td>
<td>9,317</td>
<td>9,458</td>
<td>9,640</td>
</tr>
<tr>
<td>Administrations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Municipalities and Pattaya</td>
<td>12,328</td>
<td>11,893</td>
<td>11,903</td>
<td>12,216</td>
<td>12,451</td>
</tr>
<tr>
<td>City</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Outside of municipality</td>
<td>16,561</td>
<td>17,256</td>
<td>17,420</td>
<td>17,734</td>
<td>18,074</td>
</tr>
<tr>
<td>4 Total (tons)</td>
<td>37,879</td>
<td>38,280</td>
<td>38,640</td>
<td>39,408</td>
<td>40,165</td>
</tr>
<tr>
<td>5 Total population of Thailand (106 persons)</td>
<td>61.8</td>
<td>62.4</td>
<td>62.9</td>
<td>63.4</td>
<td>63.9</td>
</tr>
<tr>
<td>6 MSW (kg/cap/day)</td>
<td>0.613</td>
<td>0.613</td>
<td>0.614</td>
<td>0.622</td>
<td>0.628</td>
</tr>
</tbody>
</table>

*Association of South East Asian Nations (ASEAN) (2005).*

Table 1: Solid waste disposal sites in Thailand

<table>
<thead>
<tr>
<th>Region</th>
<th>Number of sites</th>
<th>Disposal area (km²)</th>
<th>Amount of waste (tons/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Landfill Open dumping</td>
<td>Landfill Open dumping</td>
<td>Landfill Open dumping</td>
</tr>
<tr>
<td>Northern</td>
<td>22</td>
<td>70</td>
<td>1.4</td>
</tr>
<tr>
<td>Eastern</td>
<td>8</td>
<td>23</td>
<td>0.6</td>
</tr>
<tr>
<td>Southern</td>
<td>17</td>
<td>56</td>
<td>1.3</td>
</tr>
<tr>
<td>North-Western</td>
<td>30</td>
<td>100</td>
<td>2.2</td>
</tr>
<tr>
<td>Central</td>
<td>16</td>
<td>81</td>
<td>0.7</td>
</tr>
<tr>
<td>Bangkok</td>
<td>2</td>
<td>–</td>
<td>6.4</td>
</tr>
<tr>
<td>Total</td>
<td>95</td>
<td>330</td>
<td>12.6</td>
</tr>
</tbody>
</table>

Source: Chiemchaisri et al. (2006).

and characteristics of construction wastes is crucial for evaluating and facilitating the effective implementation of possible measures as well as existing waste management plans.

Several environmental management laws which prohibit illegal waste dumping and also give full responsibility to local administrations in developing ordinances and regulating solid waste management systems including collection fees in Thailand. One of these is the 1992 Environmental Protection Act (Ministry of Natural Resources and Environment of Thailand, 2007; Thongkaimook, 2005). A National Integrated Waste Management Plan also exists for Thailand. The plan is focused on the sustainable consumption of natural resources and the application of the ‘cradle to cradle’ concept, including control of waste generation at sources, increased waste separation to facilitate recycling and enhancement of waste utilization efficiently prior to final disposal; and a reduction by 30% of total waste generated by 2009 (Thongkaimook, 2005). To make the law more effective, the Government also aims to promote the private sector’s role in research and development for the recycling of raw materials and clean technologies; and discourage the importation of industrial waste. In addition to this, Thailand’s energy strategy and policy makes a provision for the integration of recycling into the energy conservation plan. One of the key objectives of this plan is to achieve a national recycling target of 50% by the year 2008 (Energy Research Institute, 2000).

To enhance the successful implementation of these plans, in the context of sustainability, the management and reduction of waste is reusable or recyclable (Ferguson et al., 1995). In the construction phase, construction waste is generated due to the disposal of building materials, including materials such as wood, glass and metals, which are components of MSW, are building materials, and it is unclear if these materials wastes were generated from construction activity as they could also originate from activities unrelated to construction. It is interesting to note that although detailed studies of MSW exists in Thailand (Pollution Control Department of Thailand, 2006; World Bank Group, 1999), there is a dearth of information on the management and recycling of construction waste as no system to record the amount of collected construction waste exists. Thus, there is an obvious need for a waste management system which tracks wastes from their origin as well as details their composition and other relevant parameters (e.g., volume).

The main components of construction waste in Thailand, as observed by visits to construction sites and supported by previous studies (Chanchorn, 2002), are steel reinforcement, wood, concrete, cement, bricks, and tiles. Waste generation at a construction site may result from lack of attention being paid to the size of the products used, lack of interest of contractors, and lack of knowledge about construction during design activities. Other factors such as poor materials handling, which may lead to broken parts (e.g., of bricks), are also important. About 1% to 10% by weight of purchased construction materials, depending on the type of material, is left at the site as waste. Generally, 50–80% of construction waste is reusable or recyclable (Ferguson et al., 1995). In the context of sustainability, the management and reduction of construction waste can be considered as an important issue.
because it addresses landfilling and land use related to resource consumption. In construction waste, a larger percentage of paper, plastic, etc. is expected due to packaging materials and wood retrieved from formwork and scaffolding. This is in addition to significant amounts of concrete, masonry, limestone, sandstone, metal, and wood, depending on the construction type (Bossink and Brouwers, 1996).

In Thailand, the main reason for steel reinforcement waste is that some short unusable pieces are produced when core iron is cut. This results from poor structural design and detailing. Many problems related to poor material handling also result in waste generation at construction sites. Deviations in the dimensions of cast-in-place structural elements such as slabs, beams, and columns are an important source of concrete waste. This arises due to poor design of concrete formwork systems, and flaws in the formwork assembling process. Some site managers also often order additional amounts of concrete in order to avoid interruptions in the concrete-pouring process. Sometimes this results in a surplus of concrete that is not used. A combination of factors contributes to the generation of waste from bricks and blocks. These are problems related to material delivery, such as the lack of control in the amount of bricks or blocks actually delivered and the damage of bricks or blocks during the unloading operation. Thus, poor handling and transportation could be said to be the major source of waste for bricks and blocks. The main cause of tile wastage is quite similar to those of blocks and bricks and, mainly arises because of problems related to material delivery, such as the lack of control in the concrete-pouring process. Sometimes this results in a surplus of concrete as a result of construction activity.

3.1. Estimation of construction waste generation in Thailand

The direct determination of generated quantities and composition of construction waste in Thailand is a challenging task. This is largely because construction companies are not obliged to record and report the qualitative and quantitative characteristics of the waste they generate. Consequently, in order to estimate the quantities of construction waste generated, data relevant to the type of building activity and the number and area (m²) of construction permits (see Table 1) obtained from the database of the National Statistics Organization of Thailand (2007) were utilized.

In order to evaluate the quantity of construction waste generated, the following assumptions were made: (a) new residential building activity generated 21.38 kg/m² of waste, and (b) new non-residential building generated 18.99 kg/m² (HQ Air Force Center for Environmental Excellence, 2006). The amount of construction waste was determined according to the method outlined by the HQ Air Force Center for Environmental Excellence (2006). Only waste generated as a result of construction activity from 2002–2005 was estimated in this study. The construction and maintenance of infrastructure (such as bridges and highways) were not considered due to the lack of data on these activity types. Demolition in any form was also not considered for the same reason.

The results obtained indicated that Thailand’s construction industry generated an average of 1.1 million tons of construction waste per year (see Table 3). On the basis of Thailand’s population from 2002–2005 (ASEAN, 2005), and using the construction activity time-series data for the same period (National Statistics Organization of Thailand, 2007), it was observed that the amount of construction waste generated in Thailand has grown over time. Approximately 12 kg of construction waste was generated per person in 2002; this amount had risen to approximately 18 kg in 2003 and 22 kg in 2004, with a slight decrease to about 20 kg/cap in 2005 (Table 3). This implies an average rate of construction waste generation of about 18 kg/cap/year for Thailand within this period. The slight decrease in the amount of waste produced in 2005 could be traced to the decrease in the area of new construction in 2005 when compared to that of 2004.

The computed value of construction waste generation per inhabitant for Thailand cannot be compared to international figures for construction and demolition waste generation per inhabitant, which range from about 200 kg/cap for Greece in 1996 to over 2000 kg/cap for Luxembourg and about 2800 kg/cap for Germany in the same year as available in Brodersen et al. (2002), as this study did not include waste from construction and maintenance of infrastructure (such as bridges, highways, etc.) or from any form of demolition activity as accounted for by other countries in Brodersen et al. (2002). Also, excavated soil and stones were not accounted for in this study as they were included in the waste data of some countries like Germany (Brodersen et al., 2002). Detailed figures available for Germany indicate that from the total amount of C&D generated in 2002, the main part corresponded to excavation material (65.9%), followed by building demolition waste (24.3%), road demolition waste (7.8%) and construction site waste (2.0%) (TuTech Innovation GmbH, 2006). Thus if these other waste categories had been considered in this study, the average waste generated per capita per year would substantially increase and most probably be comparable with the data of other countries. The country’s construction waste generation showed an increasing trend parallel to the development of the economy, urbanization, and rapid population growth as evidenced by government statistics and observed in many other studies (National Economic and Social Development Board of Thailand, 2006; Organization for Economic Cooperation and Development, 1998; Visvanathan et al., 2004). This correlation between economic growth and the generation of construction waste has also been observed in many countries (Christiansen and Fischer, 1999).

3.2. Potential benefits of recycling construction waste

In order to highlight the amount of potentially useful resources inherent in the waste emanating from construction activities in Thailand, the composition of waste by material type was computed according to the methodology outlined by the HQ Air Force Center for Environmental Excellence (2006). However, the rounded average composition of construction waste as specified in the methodology was not adequately disaggregated to reflect the nature of construction waste obtained in Thailand. Therefore, the percentage composition of construction waste as stated in Bergsdal (2007) was utilized as it closely reflected the types of wastes observed at construction sites in Thailand. It must be noted that a limitation of this method is that certain materials such as asbestos, which have a relatively low fraction of the total waste, appear to be insignificant when analysis is carried out on a national scale. The estimated quantity of construction waste by material type for each construction type for each year was obtained according to the equation:
where \( Q_x \) is the quantity of construction waste material \( x \) tons, \( A \) is the area of construction in \( m^2 \), \( Q_p \) the project construction waste generated in tons, \( G_{w} \), the average waste generation rate (21.38 kg/m\(^2\) of waste for new residential buildings and 18.99 kg/m\(^2\) for new non-residential buildings), and \( P_x \), the average composition of waste material \( x \) in %.

To illustrate this, for a new residential building with an area of 25,029,094 \( m^2 \), it is expected that the total construction waste generated will amount to 25,029,094 \( m^2 \times 21.38 \) kg/m\(^2\) = 535.1 \times 10^6 kg (or 535.1 \times 10^3 tons). Based on this, and using the average composition of waste wood of 14\% given in Bergsdal (2007), it is estimated that about 75 \times 10^3 tons of wood would be generated as waste. This procedure was applied for all the different construction types in Thailand within the period 2002 to 2005. The results obtained are presented in Table 4, which shows the distribution of the estimated quantity of construction waste by material type.

These are enormous quantities of resources which, if recycled, would be economically and environmentally beneficial to the country. Based on the total amount of solid waste generated in Thailand (Table 2) as well as the estimated amount of construction waste (Table 3), this study estimated that about 7.7\% of all wastes disposed of (whether in landfills or in open dumps) are construction wastes. This figure is expected to increase when wastes from the construction of infrastructure as well as maintenance and demolition activities are considered.

Varying estimates of the job creation potential inherent in recycling exist. Despite these varying estimates, it is clear that all waste management options, bulk disposal in landfills and incineration sustain the fewest jobs. For example, according to Macdonald (1998) citing the Worldwatch Institute report “for every 150,000 tons of waste, recycling creates nine jobs, incinerating creates two, and landfilling just one”. However, according to the US Environmental Protection Agency (2002), incinerating 10,000 tons of waste creates six jobs and recycling 10,000 tons of waste creates 36 jobs. By applying these assumptions to Thailand, based on the estimated annual construction waste generated, it was calculated that between 70 and 4000 jobs would be created through recycling construction waste during 2002–2005.

To illustrate the economic potential of recycling construction waste, the energy savings throughout the nation was estimated when construction waste materials such as ferrous metals, wood wastes, and concrete were recycled. Concrete is usually crushed and reused in place of virgin aggregate in a wide variety of construction applications, such as road base, fill, and as an ingredient in concrete and asphalt pavement (Conchran and Villamizar, 2007). Doing so reduces the energy associated with producing concrete using virgin aggregate material. Therefore, the benefit of concrete recycling results from the avoided energy associated with mining and processing aggregate that it replaces (US Environmental Protection Agency, 2003a). To calculate the benefit of recycling concrete to displace virgin aggregate, the following assumptions were made based on information obtained from the US Environmental Protection Agency (2003a):

(a) Process energy for the production of 1 ton of virgin aggregate = 51.3 MJ/ton

(b) Process energy for the production of 1 ton of recycled aggregate = 37.1 MJ/ton

Construction wood waste is not homogeneous, due to the diverse range of types of activities which can take place. For example wood waste could be arising from scaffolding, off-cuts, formwork and rejects. Although there may be considerable scope to recover significant quantities of wood waste from this source, not all wood residues produced are recyclable due to the condition or quantity of material produced (US Environmental Protection Agency, 2003b). Chipped or shredded wood is used as a composting bulking agent, sewage sludge bulking medium and animal bedding. Recovered wood can be used to manufacture value-added products such as medium density fiberboard and particleboard. However, these industries demand clean and consistent feedstock, which can be difficult to achieve with wood from the construction waste stream. Consequently, most wood waste usually ends up as input for products such as mulch, or used as fuel (Falk and McKeeever, 2004).

In this analysis, we assume that 50\% of all construction wood waste is recovered and used to substitute non-renewable fossil fuels in power generating plants by combustion in biomass-fired plants. It was also assumed that the lower heating value of biomass pellets from wood waste is 16.9 MJ/kg (Rakos; 2004; Hikiert, 2007). The electric efficiency of biomass combustion plants ranges from 20–30\% (Scottish Executive Environment and Rural Affairs Department Environmental Research, 2006). In this paper it is considered that the electric efficiency of biomass combustion plants is about 20\%; therefore, about 0.94 kWh\(_b\) is obtainable from 1 kg of wood. Some of the assumptions made for the calculation are shown in Table 5.

<table>
<thead>
<tr>
<th>No</th>
<th>Material</th>
<th>Average (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Asbestos</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>Hazardous waste</td>
<td>1.8</td>
</tr>
<tr>
<td>3</td>
<td>Concrete/bricks</td>
<td>354.8</td>
</tr>
<tr>
<td>4</td>
<td>Gypsum</td>
<td>48.4</td>
</tr>
<tr>
<td>5</td>
<td>Glass</td>
<td>3.6</td>
</tr>
<tr>
<td>6</td>
<td>Insulation/EPS</td>
<td>14.5</td>
</tr>
<tr>
<td>7</td>
<td>Steel (reinforcement)</td>
<td>142</td>
</tr>
<tr>
<td>8</td>
<td>Wood</td>
<td>34.9</td>
</tr>
<tr>
<td>9</td>
<td>Paper/cardboard/plastics</td>
<td>105.9</td>
</tr>
<tr>
<td>10</td>
<td>Unknown composition</td>
<td>200.6</td>
</tr>
</tbody>
</table>

| Material | Embodied energy (MJ/kg)
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel (reinforcement)</td>
<td>8.9</td>
</tr>
<tr>
<td>Wood</td>
<td>16.9 MJ/kg (primary energy)</td>
</tr>
</tbody>
</table>

Table 4 Total construction waste amounts by material (in 10^3 tons) 2002–2005

Table 5 Calculation assumptions for the recycling of construction waste

(a) Alcorn (1998).
(b) US Environmental Protection Agency (2003b).
(c) Assumed.
(d) Rakos (2004), Hikiert (2007).
The results obtained indicate that an average primary energy savings of about $3.0 \times 10^5$ Gj per year during 2002–2005 could be achieved by recycling the construction materials examined. Fig. 3 shows the relative contribution of the three materials assessed to this savings. This amount is expected to increase if other building materials are recovered and recycled efficiently.

It was observed that the use of waste wood for electric energy had the largest contribution to the total energy savings with about 89%. The recycling of ferrous metals followed next with 8%, and the down-cycling of concrete to aggregates contributed about 3%. One factor responsible for the relatively low contribution of concrete to this energy savings could be attributed principally to the low difference in energy requirements between virgin and recycled production of aggregates. Another reason for the relatively low contribution of ferrous metals and concrete materials was because this study did not include the quantities of these materials generated from demolition activity. If these had been accounted for, then it is expected that the energy savings attributable to their recycling could be expected to be much higher. This is because, according to Myhre (2003), both materials have the largest percentages when all the waste generated from construction, renovation and demolition activities are accounted for. This is clearly illustrated when the material contribution to energy savings as a result of recycling demolition waste from a 60,000 m² commercial building (assumed) is assessed. It should be noted that this estimation is simple for illustrative purpose and is based on scenario analysis as the data required to actually model waste generation from demolition activity within Thailand’s building stock is unavailable as mentioned earlier. The composition of demolition waste as obtained in Bergsdal (2007) was utilized. The assumptions for recycling the recovered materials are as stated earlier and also in Table 5.

An assessment of the recycling of recovered demolition waste materials was made for a typical commercial building in Thailand with an assumed gross floor area of 60,000 m² and concrete envelope. The average quantities of the different materials from demolition of the building were computed using Eq. (1) and the same procedure as that for utilized for determining waste materials generated from new construction. Wood was assumed to be used for process heat, ferrous metals substituted virgin materials and the down-cycling of concrete was used as aggregates in concrete or backfilling in new construction. For example the average quantity of metal generated from demolition was computed according toEq. (1) based on an assumed area of construction of 60,000 m², an average waste generation rate of 18.99 kg/m² for new non-residential buildings and an average composition of waste metal of 4%. Substitution in (1) yields $1.14 \times 10^3$ tons of waste generated from the building demolition, of which approximately 50 tons is metals. Assuming 30% of all metal waste is recovered and recycled (Table 5), then the total amount of metal recovered would be 15 tons. The production of virgin metals requires 8.9 MJ/kg (Table 5). Therefore the energy required to produce 15 tons of virgin metal is $15,000 \times 8.9 \times 10^3 = 1.34 \times 10^5$ MJ. Recycling the metals results in energy savings of up to 60%. Thus, the production of recycled metals would result in an energy savings of $1.34 \times 10^5 \times 0.6 = 7.9 \times 10^4$ MJ of energy. The same procedure was applied in determining the savings obtainable for all the materials considered in the scenario and the results aggregated.

For the scenario assessed, the results indicated that about $2.2 \times 10^5$ Gj of energy could be saved for the assumed case study 60,000 m² building. Of this amount, the largest share of about 57% originated from the recycling of wood. Ferrous metals and concrete followed next with contributions of about 37% and 6%, respectively. This result shows an increased contribution of both ferrous metals and concrete recycling to energy savings when compared to their relative proportions obtained for the recycling of their construction waste scenario. The difference in relative proportions of energy savings between the construction and demolition scenarios is principally due to the fact that the waste fractions of these two materials are much higher during demolition than construction as explained earlier. Also because demolition clearly dominates total waste amounts, the profile of the relative contributions of recycling different materials to energy savings in Thailand is expected to be different from the result presented in Fig. 3 when C&D waste data based on a national scale characterization study is utilized for the analysis. It should be noted that the results obtained from this scenario analysis are largely dependent on the composition of C&D waste utilized, which varies in different countries.

It is important to realize that the computation was carried out simply to illustrate the benefit of recycling. This, however, does not imply that other strategies cannot be applied to manage construction waste. For example, the recycling of wood waste for fuel, pulpwod, and feedstock for products such as particleboard depends on the quality and quantity of the recovered material as well as economic and environmental considerations (US Energy Information Administration, 2006). Consequently the benefits of recycling some materials such as construction wood waste should only be assessed within an integrated waste management model for which adequate information is presently unavailable.

Recycling, being one of the strategies in the minimization of waste, offers several benefits – reduction in demand for new resources, reduction of transport and production energy costs and use of waste which would otherwise be lost to landfill sites. Although there are many material recycling schemes recommended, actual administering of C&D waste recycling is limited to a few types of solid wastes. Therefore, when considering a recyclable material, the economy, compatibility with other materials and material properties are three major considerations. Many viable technologies for recycling construction waste exist (Tam and Tam, 2006b). However, there is a lack of knowledge within the construction industry regarding these. Education awareness campaigns could serve as vehicles to promote the use of these technologies.

### 4. Conclusions and recommendations

Thailand’s construction industry generated an average of 1.1 million tons of construction waste per year during 2002–2005. Most of these wastes were dumped illegally and others were landfill filled. This is a loss of valuable economic resources. To develop a sustainable construction industry in Thailand, the Integrated National Waste Management plan must be fully implemented together with measures that encourage the recovery and recycling.
of construction waste. Effort must also be directed at minimizing construction waste generation by improving the managerial capacity of companies at the design, procurement, and production stages. This can be achieved by educating stakeholders on the importance and benefits (e.g., reduction of transportation and landfill disposal costs) of implementing cleaner production in waste management as an opportunity for the effective reduction of waste generation and its disposal. Effective recovery and recycling of construction waste has the potential to create jobs and also reduce energy consumption in the country. One of the key limitations to this study was the lack of construction and demolition waste data in Thailand. Without this, it is hard to plan future requirements for construction waste management or even improve the performance of the construction industry. To attain the goals of the national waste management plan and enhance the recycling of construction waste in Thailand, it is recommended that an inventory of all construction and demolition waste generated in the country be created. This will provide information that can be used to assess the feasibility of large scale recycling of construction waste. Finally, there must be fruitful cooperation between the waste management authorities, and management initiatives should include effective measures for the documentation of waste streams and focus on the main cities from which these wastes originate.

References


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