Warm Mix Asphalt with Reclaimed Asphalt Pavement—A Solution for Sustainable Infrastructure Development

Thi Yen Lu and Ngoc Lan Nguyen

Abstract While almost all asphalt paving contractors in Vietnam are using virgin, non-renewable materials (i.e., aggregates and bitumen) to produce conventional hot mix asphalt (HMA), most contractors in the United States, Europe and Japan are producing warm mix asphalt (WMA) with reclaimed asphalt pavement (RAP). WMA can be produced and paved at lower temperatures, reducing energy consumption and emissions released during production and paving of asphalt mixtures. Use of RAP can reduce the demand for non-renewable resources. When RAP is used in WMA, their environmental benefits can be combined, making the produced mixture more sustainable. This study presents a life-cycle assessment (LCA) to compare the environmental benefits of WMA with RAP to those of the conventional HMA currently produced by most of the asphalt producers in Vietnam. The WMA mixtures with 20–50% RAP were designed to have performance similar to the conventional HMA in the LCA. Based on this LCA analysis, it was determined that WMA with the addition of from 20 to 50% RAP provides a reduction of 16.6–27.0% global warming (CO_2-eq) and 17.8–28.7% energy consumption impact of HMA when it is designed to have the same performance as the conventional HMA.

Keywords Hot mix asphalt · Warm mix asphalt with RAP · Reclaimed Asphalt Pavement · Greenhouse gas emissions · Energy consumption · LCA

1 Introduction

In recent years, the asphalt pavement industry has continuously developed new technologies with the aim of improving not only economic and technical efficiency but also environmental efficiency [1]. In developed countries such as the United States,

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Europe, Japan and South Korea, most contractors are producing warm mix asphalt (WMA) with reclaimed asphalt pavement (RAP) as an alternative to traditional hot mix asphalt (HMA) [2]. WMA can be produced and paved at a temperature of about 28 °C lower than HMA [3], thus reducing energy consumption and emissions released during manufacturing and paving of asphalt mixtures. Using RAP as partial replacement to the new aggregate can save non-renewable natural resources and reduce pressure for landfill if they are disposed. When RAP is used in WMA, their environmental benefits can be combined, making the produced mixture more sustainable. A series of studies have been conducted to compare the environmental impacts between HMA and WMA mixtures, which showed that WMA with RAP addition (WMRAP) had the advantages of lower energy consumption by 25–35%, fewer greenhouse gases by 25–40% and better working condition during mixing and paving process [4–6].

Although WMRAP is considered as an environmentally friendly material, currently most road infrastructure construction projects in Vietnam still use non-renewable natural materials to produce conventional HMA. WMRAP is still a relatively new technology and is attracting the attention of regulatory agencies and construction contractors. The initial experimental studies in the laboratory and the field show that the technical properties of WMA with the addition of from 20 to 50% RAP meet the same technical performance as for HMA [7]. However, in order to apply this new technology, besides technical studies, it is necessary to conduct research on calculating and quantifying the environmental impact of WMRAP technology in actual conditions in Vietnam as basis to compare and choose solutions for sustainable infrastructure development compared to traditional HMA technology.

The life cycle assessment (LCA) method is currently considered as the most effective method for quantifying and comparing the environmental impacts of pavement materials throughout their entire life cycle, including extracting and processing of raw materials, manufacturing, transportation, utilization, maintenance, recycling, and final disposal during end-of-life stage [8]. However, due to the relatively new technique of WMRAP for pavement construction in Vietnam, to date, the LCA study of WMRAP pavement was still rarely conducted.

The purpose of this study is to quantify and evaluate the environmental efficiency (energy consumption and greenhouse gas emissions) of WMRAP technology compared to traditional HMA technology, using LCA method. Initial research results will serve as a basis for determining sustainable infrastructure development solutions in addition to technical and economic criteria.

2 Life Cycle Assessment Method

According to ISO14040 [9], LCA studies are conducted through four stages, including: goal and scope definition, inventory analysis, environmental impact assess-ment and life cycle interpretation.

2.1 Goal and Scope Definition

In this paper, the study subjects were WMRAP mixes using Zycotherm additive (0.15% content of asphalt binder) with RAP rates of 20, 30, 40 and 50%. The reference sample was hot mix asphalt (0% RAP). The design composition of the concrete mixtures is shown in Table 1.

The aim of the study is to compare the environmental performance in terms of energy consumption and greenhouse gas (GHG) emissions of WMRAP technology to traditional HMA technology.

System boundary and functional unit are two vital factors to be defined in the scope of LCA study. The functional unit is defined as a quantitative benchmark unit that should represent the function of the analyzed system. The functional unit in this study is one ton of asphalt mixtures during their life cycle. Typically, pavement material life cycle consists of the following stages: raw material production, transportation, construction, use, maintenance, and final disposal at the end of life

Table 1 Composition and properties of different mixtures

Composition	Asphalt mixtures				
	HMA (0%RAP)	WMRAP			
		20% RAP	30% RAP	40% RAP	50% RAP
RAP	–	19	28.5	37.9	47.4
$Agg._{12.5}$	19	18.1	16.1	13.3	12.3
$Agg._{9.5}$	28.5	18.1	18	16.1	14.2
$Agg._{4.75}$	42.8	36.1	28.5	23.7	17
Filler	4.8	3.8	3.8	3.8	3.8
$P_{b(RAP)}$	–	0.8	1.1	1.5	1.9
P_{bn}	5	4.2	4.0	3.7	3.4
Total	100.0	100.0	100.0	100.0	100.0
Properties of Mixtures					
V_a (%)	4.5	3.9	41	4.1	4.3
VMA (%)	15.7	14.1	14.1	14.3	14.3
VFA (%)	71.5	72.1	70.7	70.9	70.1
P_{ba} (%)	0.3	0.72	0.70	0.95	1.05
P_{be} (%)	4.7	4.32	4.44	4.30	4.31
$P_{0.075}/P_{be}$	0.8	0.85	0.83	0.86	0.86
MS (kN)	11.3	13.83	15.03	16.06	16.64
MF (mm)	3.5	3.62	3.58	3.58	3.56

V_a = Air voids; VMA = Voids in the mineral aggregate; VFA = Voids filled with asphalt; P_{ba} = Absorbed binder content; P_{be} = Effective binder content; $P_{0.075}/P_{be}$ = Dust-to-binder ratio; MS = Marshall Stability; MF = Marshall Flow; $P_{b(RAP)}$ = content of asphalt binder of RAP (%); P_{bn} = virgin asphalt binder content (disposal/reuse/recycle). The environmental impacts in the use stage of pavement are mainly including the fossil fuel combustion of the vehicle, which is assumed to be the same for both WMA and HMA pavements. Therefore, the pavement use stage was not included in this study. The system boundary and unit processes are shown in Fig. 1.

In which, the pavement maintenance stage was considered with the following assumptions:

– Damaged asphalt layers was scraped off and paved a new layer of asphalt mixture produced at the concrete plant according to 2 options:

+ Recycling old pavement: reclaimed asphalt pavement was transported to the concrete plant and regenerated to produce WMRAP mixture to replace the old pavement.

+ Not recycling old pavement: reclaimed asphalt pavement was transported to the landfill for disposal, the pavement is replaced with HMA mixture.

– The maintenance area accounted for 20% of the road surface area obtained when constructing 1 functional unit (meaning 1 ton of asphalt mixture).

– RAP transport distance to the concrete plant is the same to the landfill.

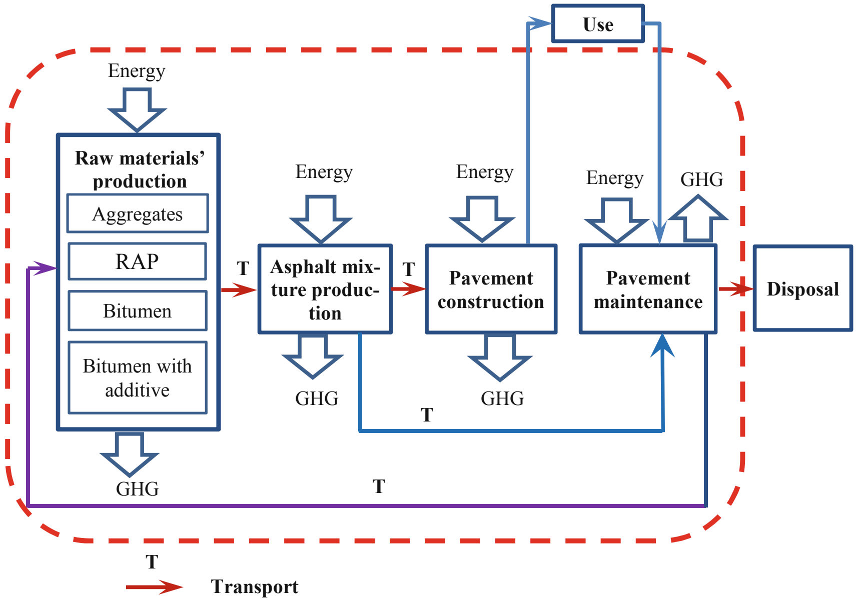


Fig. 1 System boundary of LCA model in this study

2.2 Inventory Analysis and Environmental Impact Assessment

During this stage, it is necessary to determine the amount of raw materials, energy, and waste discharged into the environment over the life cycle of the product.

For HMA plants that have been operating for many years under a steady process, data inventory of raw material and input energy can be determined from the plant statistics. Therefore, the input data for the unit stages and processes of HMA technology is surveyed and collected directly at the HMA plant. However, WMRAP is a new technology to Vietnam and production projects are just pilot so there is no statistics on energy consumption norms. Therefore, for WMRAP, the energy input data in the production stage is determined by the calculation method presented in the study [10].

The output data on GHG emissions (CO_2, CH_4 and N_2O) was determined by using emission factors under Intergovernmental Panel on Climate Change guidelines [11] according to the formula:

$$GHG_j = \sum_{i=1}^{n} \sum_{j=1}^{3} AD_i * Q_i * \mathrm{EF}_j \quad (1)$$

In which: GHG_j is the greenhouse gas j; AD_i is the amount of energy consumption in stage i (liter of diesel oil, kg of fuel oil or kWh of electricity…); Q_i is the conversion coefficient of energy units in stage i (MJ/liter of diesel oil, MJ/kg of FO oil, MJ/kWh of electricity…); EF_j is the GHG emission factor j (g/MJ).

The conversion coefficient of energy units is shown in Table 2. The GHG emission factor of fuel consumption is taken at default value [11], the electricity emission factor of Vietnam is taken according to the latest published data of the Department of Climate Change—Ministry of Natural Resources and Environment (Table 3) [13].

Table 2 Conversion coefficient of energy unit [12]

Energy	Electricity	Diesel	Fuel oil
Unit	kWh	Lit	kg
Conversion coefficient of energy units, MJ	3.6	36.845	41.451

Table 3 GHG emission factor

Type of energy		Fuel oil	Diesel	Electricity
Emission factor, g/MJ	CO_2	77.4	74.1	253.6
	CH_4	0.003	0.003	–
	N_2O	0.0006	0.0006	–

Since each type of GHG released into the atmosphere has a different global warming effect, they are often converted to CO_2 equivalent values and called equivalent CO_2 or CO_2-eq by using GWP coefficient (Global Warming Potential). Then, the total CO_2-eq emissions were calculated by the formula [11]:

$$CO_2 - eq = \sum_{j=1}^{3} GHG_j * GWP_j \qquad (2)$$

3 Results and Discussion

3.1 Energy Consumption

As shown in Fig. 2, the calculation results indicate that the total energy consumption during life cycle of HMA is higher than that of WMRAP. In the life cycle of HMA, it is required to use an energy of 530.0 MJ/ton. Each stage in the HMA life cycle has different energy demands, in which, the asphalt mixture production phase of HMA is the main source of energy consumption, accounting for 55.7% of total energy demand (Fig. 2). So, reducing the aggregate heating temperature is the more effective solution to reduce energy consumption compared to other stages.

The RAP content to replace new aggregates has an impact on energy consumption in the life cycle of the WMRAP. The results in Fig. 2 show a reduction in energy consumption due to the higher rate of RAP. The HMA mixture was produced without the addition of RAP, while the WMRAP mixtures were produced with 20, 30, 40 and 50% RAP. These RAP rate increasing account for decreases in energy consumption, which were determined as 435.9 MJ/ton, 416.9 MJ/ton, 397.4 MJ/ton and 377.8 MJ/ton, respectively. This means that the higher the RAP content used in the WMRAP mixtures the greater the reduction in energy consumption compared to

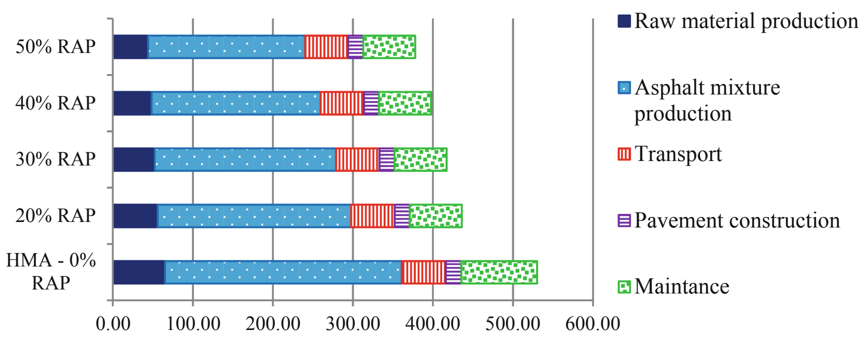


Fig. 2 Energy comsumption in life cycle of WMRAP and HMA

Table 4 Environmental efficiency of WMRAP technology compared to HMA technology

WMRAP mixture	20% RAP	30% RAP	40% RAP	50% RAP
Energy consumption reduction, %	17.8	21.3	25.0	28.7
GHG emission reduction, %	16.6	19.6	23.3	27.0

the HMA mixture. Based on this LCA analysis, it was determined that WMA with the addition of from 20 to 50% RAP provides a reduction of 17.8–28.7% energy consumption (Table 4).

3.2 Greenhouse Gas Emissions

Table 5 presents the total of GHG emissions during life cycle of WMRAP and HMA mixtures. The data in Table 5 shows a reduction of GHG emissions for all WMRAP mixtures evaluated; emissions were higher for the reference mixture with 0% RAP. Less GHG emissions was obtained in WMRAP technology with higher RAP content. Compared with HMA technology, the GHG emissions were reduced from 16.6% to 27.0%, respectively with the RAP content of 20–50% (Table 4). Thus, it can be concluded that when the RAP content in the asphalt mixture increases, the higher the efficiency of GHG emission reduction is achieved.

Analysis of GHG emissions from different sources during the life cycle of HMA shows that nearly 42% of total emissions come from mixture production phase (Fig. 3). In this stage, as shown in Fig. 4, the emissions from burning fuel to heat the new aggregate (at temperature180 °C) account the highest portion of the total energy (nearly 77%). It can be seen that the aggregate heating temperature is an important factor affecting greenhouse gas emissions. Decreasing aggregate heating temperature lead to reduce GHG emissions.

Thus, the results of environmental impact analysis by LCA method are the basis for applying the solutions on reducing GHG emissions for traditional HMA technology. In which, the most effective solution to minimize GHG emissions is to reduce emissions at the stage with the highest emission rate, that is to reduce the temperature of mixture production. Moreover, increasing RAP content to replace new aggregate is also an effective solution to reduce GHG emissions.

4 Conclusion

In this study, a comparative comprehensive life cycle assessment (LCA) was conducted for WMA and HMA pavements. According to research results, the specific conclusions can be drawn as follows:

Table 5 Total GHG emissions in the asphalt mixtures life cycle

Asphalt mixture	GHG emissions in stage, kg CO_2-eq /ton					Total GHG emissions, kg CO_2-eq/ton
	Raw material prodution	Asphalt mixture production	Transpotation	Pavement construction	Maintenance	
HMA—0% RAP	18.87	25.58	4.13	1.46	11.13	61.17
WMRAP—20% RAP	16.10	21.39	4.08	1.41	8.06	51.04
WMRAP—30% RAP	15.42	20.2	4.06	1.41	8.06	49.16
WMRAP—40% RAP	14.38	19.02	4.04	1.41	8.06	46.92
WMRAP—50% RAP	13.35	17.83	4.02	1.41	8.06	44.68

Fig. 3 Proportion of GHG emissions in life cycle of HMA

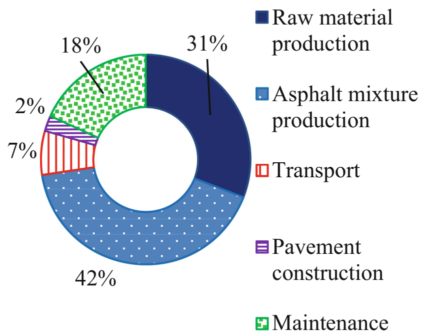
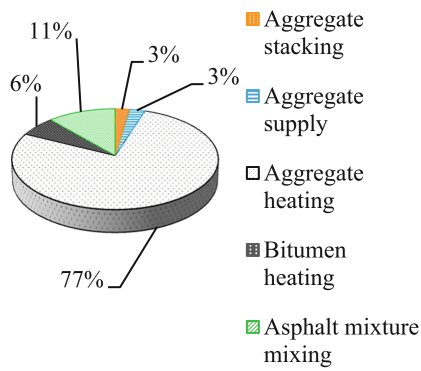


Fig. 4 Proportion of GHG emissions sources in mixture production of HMA



- WMRAP technology may reduce GHG emissions and energy consumption during the life cycle compared to HMA technology. Environmental burden reduction efficiency of WMRAP technology depends on the RAP rate used: as the RAP content increases, the environmental benefits of WMRAP become even more pronounced. The increasing of RAP from 20–50% provides a reduction of 16.6–27.0% global warming (CO_2-eq) and 17.8–28.7% energy consumption impact of HMA.
- WMRAP technology can reduce the need for exploitation and use of non-renewable natural resources as part of the new aggregate and asphalt is replaced by RAP and reduce land use for construction waste landfill.

In conclusion, the environmental benefits of WMRAP technology have contributed to the improvement and reduction of environmental issues in the construction materials industry. In addition, the GHG emission reduction allows asphalt mixing plants to be installed near residential areas which has high demand of this construction material and also has more stringent environmental requirements.

The environmental benefits of WMRAP technology may constitute an important tool for engineers and legislators in selecting more sustainable pavement technology to use in infrastructure design, in terms of both technical and economic performance. In this context, WMRAP technology has the prospect of better social and market acceptance.

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