Air Pollutant Emissions from Paddy Residues Open Burning and their Potential for Bioenergy in the Greater Mekong Sub-Region (Cambodia, Lao PDR, Thailand and Vietnam)

Savitri Garivait, Sébastien Bonnet and Orachorn Kamnoed

Abstract— *An inventory of emission and emission factors of carbon monoxide (CO) and total particulate matter or aerosol (TPM) from biomass open burning in the Greater Mekong Sub-Region (GMS) was developed, in order to document the characteristics of this significant source of air pollutants in the region. This was conducted using remote sensing data in combination with ground-based observations, and vegetation land-use in each country. First, we prepared monthly gridded emission maps, to identify vegetation types subjected to open burning, and to investigate its spatial and temporal distribution. Preliminary results indicate that the major types of vegetation land use subjected to open burning in the GMS are forests and paddy fields. For the latter, the amount of rice straw and stubbles available for open burning in the GMS countries is estimated and converted to the energy equivalent in order to assess their potential as renewable energy resource at the national and regional scale. Results obtained in the case of Thailand show that about 48 million tons of rice straw and stubbles are available to open burning annually. Considering their calorific values for heat production, rice straw and stubbles may give rise to about 680 PJ.*

Keywords— **Bioenergy, Emissions Inventory, Open Burning, Paddy Field Residues, Greater Mekong Sub-Region.**

1. INTRODUCTION

Biomass open burning is defined as the combustion of the world's living and dead vegetation, including grasslands, forests and agricultural lands after harvest for land clearing and land-use change. It has been recognized as a key driver for global change, since it constitutes one of the major sources of gaseous and particulate emissions to the atmosphere. These latter contribute to global environmental change by affecting local, regional, and global air quality as well as by disrupting rainfall patterns. In the ASEAN region, they lead to an air quality problem named transboundary haze, especially during the dry season in both hemispheres [1-2]. In the northern hemisphere the peak period is observed during January to March in the region including Cambodia, Lao PDR, Myanmar, Thailand and Vietnam, and in the southern hemisphere during August to October, with a transport of haze from Indonesia up to the southern part of Thailand. To remediate this regional air quality issue, which was the origin of high number of patients among the population suffering of respiratory diseases, the ASEAN approved to set up the ASEAN Agreement on Transboundary Haze on a voluntary basis of participation and ratification. Once a member country accepted to ratify, the National Master Plan on Open Burning Control and the Open Burning Control Plan of Implementation should be developed and implemented. However, there is still a lack of reliable and up-to-date information on the spatial and temporal distribution of biomass open burning emissions in Asia, and more particularly in the Greater Mekong Sub-Region (GMS) including Cambodia, Lao PDR, Thailand and Vietnam, which could support the regional air quality modeling and monitoring in order to better evaluate their impacts on regional air quality and climate.

As part of this process, this research study focused on a spatial and temporal inventory of biomass open burning in the GMS, using remote sensing data in combination with ground-based observations, in order to develop a database of emissions and appropriate emission factors of carbon monoxide (CO) and total particulate matter or aerosol (TPM). Preliminary results indicate that the major types of vegetation land use subjected to open burning in the GMS are forests and paddy fields. Rice is the major economic crop in the GMS countries; the burning of rice residues, i.e. straw and stubbles, may affect not only local and regional air quality, but also national economy through the impacts of these burning activities on the soil structure, and so on the production yield.

In this study, a monthly 12 km x 12 km gridded emission maps of CO and TPM associated to open burning of paddy fields in the GMS was developed, in order to investigate spatial and temporal distribution. The obtained results are analyzed and discussed, with a focus on emission characteristics of this type of air pollutants source. Their contributions to the formulation of control strategies and mitigation policy measures, in order to support the ASEAN Transboundary Haze Agreement, are also evaluated. The amounts of rice straw and stubbles available for open burning in the GMS countries are also estimated and converted into energy equivalent in order to assess their potential, at the national and regional scale, for renewable energy.

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2. METHODOLOGY

Vegetation coverage of GMS

To classify the vegetation coverage of the GMS, a Geographic Information System (GIS) was developed incorporating a database of digital detailed land-use maps of Thailand, Cambodia, Lao PDR and Vietnam. Geographic data and their associated attributes were collected for the base year 2000 from governmental agencies in charge of land development, land use management, national statistics. The two main types of vegetation being accounted in this study are forest and paddy fields, and a 1:250,000 scale map including only 3 types of land-use (forest, paddy, and others comprising vegetation, constructed area, etc.) was created for each country of the region, in order to serve as a base GIS layer for classifying emission areas (Fig. 1). In the case of Vietnam, bush was also included to better account for vegetation frequently subjected to open burning.

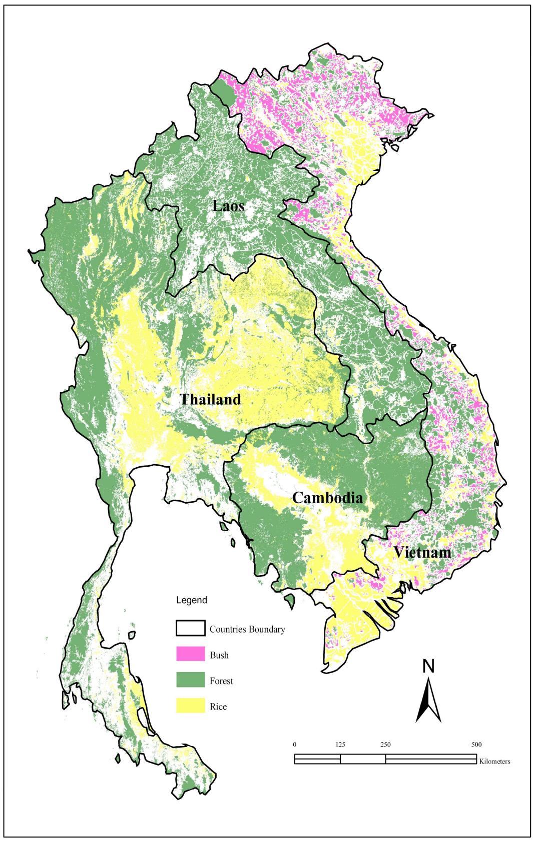

Fig.1. GMS vegetation map – Base year 2000

Figure 1 indicates that paddy fields are mostly located in the central part of Cambodia, in the central and northeastern part of Thailand, and in the northern part along the border with China and in the southern part of Vietnam. In the case of Lao PDR, the main vegetation of the country is forest, and lands dedicated to paddy are still limited and spread throughout the country. A summary of land surface of each type of vegetation is reported in Table 1.

Table 1. Land surface of forest and paddy fields in GMS

Type	Thailand	Cambodia	Lao PDR	Vietnam	Total in GMS
Forest km^2 Mha (% NL)	170,157 17.02 (33%)	108,990 10.90 (61%)	142,602 14.26 (60%)	58,613 5.86 (18%)	480,362 48.04
Paddy km^2 Mha (% NL)	105,754 10.58 (21%)	17,024 1.70 (9%)	2,556 0.26 (1%)	48,611 4.86 (15%)	173,945 17.39
NL* km^2 Mha	514,361 51.44	181,035 18.10	236,80 23.68	331,033 33.10	1,263,229 126.32

**NL : National Land*

From Table 1, Cambodia and Lao PDR are observed to be the two countries of the region to be mainly covered by forest, i.e. about 60% of the total national land, while Thailand and Vietnam dedicate 15-20% of their national land for rice cultivation.

Assessment of biomass burning activities using satellite data

Biomass burning activity was assessed using remote sensing data. This method provides an overview of geographic positions and temporal changes of biomass burning areas. The satellite data used in this study are fire hotspots retrieved from satellite launched under the Asia-Pacific Network for Disaster Mitigation Using Earth Observation Satellite (ANDES) research program. The DMSP-OLS sensor enables to detect areas where a temperature higher than a threshold, qualified as reference temperature of an open burning (>150 $^{\circ}$C), is observed and named as hotspots. The resolution of the detection instrument is 2.7 km x 2.7 km, which is considered as a coarse resolution for satellite detection; however it is sufficiently fine for geographically indicating the position of biomass burning area, and for calculation of the associated emissions. Based on this resolution, the size of a hotspot is assumed to be equal to 2.7 km x 2.7 km. The ANDES hotspots data were available daily from 1998-2004. The base year of hotspots' data collection for this study was the year 2002, since for this year no major interruption of satellite data collection was noticed; hotspots had been collected for the whole year enabling to document the temporal changes of open burning activity in the region.

The daily data were first processed into monthly data of fire hotspots in the form of a GIS map, in order to investigate the seasonal variability over a year. An example of monthly hotspots map is given in Figure 2. Each hotspot was classified according to the vegetation in which it occurred, by overlaying the monthly hotspots map to the vegetation coverage map, in order to qualitatively and quantitatively assesses the type of biomass subjected to open burning.

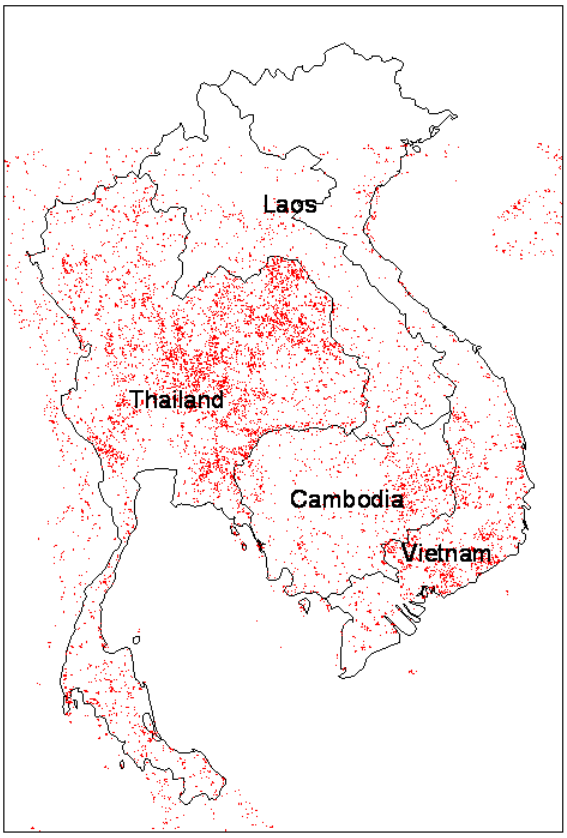

Fig.2. An example of monthly hotspots map - 2002

In order to systematically geo-reference the position of the hotspots, a grid map with a resolution of 12 km x 12 km was developed.

Estimation of air pollutants emission from biomass open burning – Calculation method

The emissions of air pollutants from biomass open burning on a yearly basis can be estimated using the equations, initially developed by Seiler and Crutzen [3], based on the basic chemical reaction of combustion, which represents the relationship between the combustion process and its emission as follows.

$$E_x = M \times EF_x \qquad (1)$$

where, E_x is the emission of the pollutant x (g/year), M is the mass of dry matter burned (kg dm/year), and EF_x the emission factor of the pollutant x (g/kg dm burned).

From Equation 1, it is evident that before estimating the emission, M and EF_x should be first quantified.

a) Estimation of dry matter biomass burned:

- *Forest*

In order to estimate the amount of biomass burned per year as a result of forest fires the following general equation is used:

$$M = A \times B \times \alpha \qquad (2)$$

where, M is the amount of biomass burned per year, (kg/year), A is the area of forest burned per year (m^2 per year), B is the above ground biomass density (kg/m^2), and α is the fraction of above ground biomass burned.

- *Agricultural crop*

In the case of crop residues burning, the amount of biomass burned is determined using a modified version of the equation given in the IPCC revised guidelines (1996) and also used in works of Hao and Liu (1994) or Streets et al. (2003) as follows.

$$M = P \times D \times B \times F \times \alpha \qquad (3)$$

where, M is the total mass of crop residue burned in field (kg/year), P is the crop production ($kg/\ m^2.year$), D is the crop specific residue to product ratio, B is the dry matter fraction (or biomass load if P is expressed in unit of surface instead of unit of mass), F is the percentage of dry matter residues burned in field, and α is the burning efficiency.

The data used in this study and their sources both for forest fires and rice residues burning, are reported in Table 2.

Table 2. Estimates of tropical forest biomass and crop residues burned in Asia

	Biomass load range (kg/m^2)		Burning efficiency	
Tropical Forest	10^a		0.2^b	
Crops	Residue-to-crop ratio	Dry matter fraction	Dry matter burned in field	Burning efficiency
Rice	1.76^c	$0.85^{d,e,f}$	$25\%^{d,e}$	$89\%^e$

[a]IPPC (1996) [4]; [b]Levine (2000)[5]; [c]Koopmans and Koppejan (1997)[6], [d]Hao and Liu (1994)[7]; [e]Streets et al., (2003)[8]; [f]OEPP, Thailand (1990)[9]

b) Estimation of emission factors of air pollutants of interest

A comprehensive study by Andreae and Merlet (2001) provides emission factors for various types of biomass burning including tropical forest and crop residues. The emission factors reported by Andreae and Merlet [10] come from an updated review of practically all research works performed over the last 30 years on emission factors measurements worldwide. The emission factors of air pollutants of interest are reported in Table 3. For Total Particulate Matter (TPM) or aerosols, the emission factors used are from Levine (2000), since they have been obtained from experiments representative of burning conditions occurred in Asia (Table 3).

In order to systematically assess the open burning emissions of a given pollutant, a grid map with a resolution of 12 km x 12 km, identical to the map used for evaluating open burning activities, was set by incorporating the equations and data required to calculate air pollutant emissions, as inputs into the GIS database. Monthly emission maps were prepared for each of the pollutants considered in this research study.

Table 3. Emission Factors of air pollutants of interest

Compounds	Tropical Forest	Crop residues
	Emission Factors (g/kg)[a]	
CO_2	1580 ± 90	1515 ± 177
CO	104 ± 20	92 ± 84
CH_4	6.8 ± 2.0	2.7
N_2O	0.20	0.07
NOx	1.6 ± 0.7	2.5 ± 1.0
TPM*	20[b]	10[b]

[a]Andrea and Merlet (2001)[10]; [b]Levine (2000)

Estimation of amount of straw and stubbles consumed and corresponding energy released by open burning

Stubble corresponds to the lower part of the plant next to the root, which generally stays on the ground after harvest. Straw constitutes the part coming with the grain during harvesting. Based on field surveys in Thailand and Cambodia, it is to underline that in the past, straw was moved out of the fields to be used as animal fodder, and stubbles served as additional fodder for cattle and buffalo labors as well as supplement organic matter to be incorporated back into the soil during land preparation for the new plantation. At present, with intensification of rice farming, animal labors are replaced by machines, and straw and stubbles are being more extensively burned in the field, especially in the region where water resources are sufficient to enable the plantation of secondary rice. In addition, the length of straw and stubbles varies greatly with species and harvesting methods. A paddy field harvested mechanically leaves in the field stubbles of 20-30 cm height, while when manually collected leaves stubbles of over 50 cm height. Also, long-lived (about 180 days) species planted in some parts of northeastern region of Thailand may provide straw of 1.5-2.0 m in length, while short-lived species (90-120 days) would have a length of less than 1.2 m.

The amount of straw and stubbles consumed by open burning can be estimated using the residues-to-product ratio (RPR) or D in the calculation of emission estimates based on the following equation.

$$M_{res} = A \times P \times RPR_{res} \quad (4)$$

where, M_{res} is the total mass of considered crop residue after harvest (Mt), A is the cultivated area (Mha), P is the crop production (t/ha), RPR_{res} is the specific considered residue-to-product ratio.

In this study, A and P are collected from Food and Agriculture Organization (FAO) statistics (FAOSTAT) for the year 2002. For RPR, the calculations were conducted using two values: (1) the value of 1.757 reported by Koopmans and Koppejan [6], and (2) the value of 0.750 obtained based on field survey in this study. The difference observed between the two values is due to the quantity of stubbles left in the field.

Regarding the corresponding energy release, this represents the energy content of the residues, and was estimated using the following equation.

$$E = M_{res} \times CV \quad (4)$$

where, E is the energy of the total crop residue after harvest (PJ), M_{res} is the total mass of crop residue after harvest (Mt), CV is the calorific value of the residue considered (MJ/kg).

Straw and stubbles have the same CV value of 14.00 MJ/kg [11].

3. RESULTS AND DISCUSSION

Biomass open burning activities

The biomass open burning activities observed by ANDES satellite for Thailand, Cambodia, Lao PDR and Vietnam, are reported in Figure 3, for both fire counts and burned areas. This latter is converted from fire counts based on a satellite sensor resolution of 2.7 km x 2.7 km.

Results from Figure 2 indicate that the peak season of forest fires in Thailand, Cambodia, Lao PDR, and Vietnam runs from January to April. Indeed, forest fires are significantly detected from October onward, i.e. starting month of the dry season in the region.

Regarding paddy field burnings, the peak season is also observed during the January-April period in Thailand, Lao PDR and Cambodia, while Vietnam displays a different pattern with frequent burning occurring throughout the year. Also with regards to the intensity of paddy field burning, Thailand and Vietnam are far ahead. The particular seasonal pattern of paddy field burning observed for Vietnam seems to confirm an agro-intensification of rice production in this country.

The frequency of fires, quantified by fire counts, indicates that forest is much more affected by open burning than paddy fields, although there are uncertainties in these estimations, notably in the case of satellite detection of rice residues open burning.

Monthly emission maps

An example of monthly emission maps of TPM during the peak period (January-April 2002) is reported in Figure 4, in order to investigate the spatial distribution of biomass burning during the high season of biomass burning.

From Figure 4, it is observed that paddy fields open burning occurs in Thailand in the central and in the northeastern regions of the country, especially in January and February. In Cambodia, burning is also intense during these two months and is located in the central part around the Mekong delta. In the case of Lao PDR, as paddy fields and forest coexist, and the rice cultivation land is very limited, the burning is observed to spread throughout the country with very low intensity or frequency. Finally for Vietnam, only rice fields in the south along the border with Cambodia are affected by burning and are characterized by a similar intensity throughout the four months studied, confirming a possible intensification of rice farming in this region.

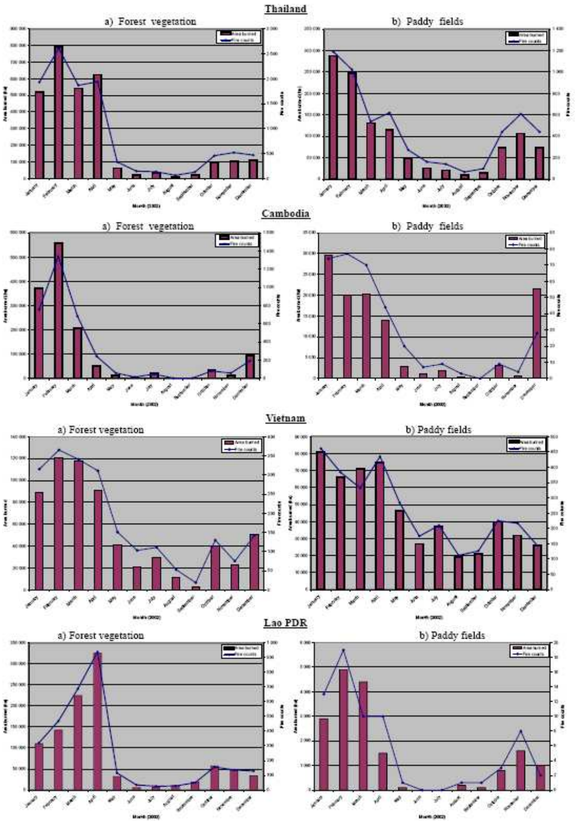

Fig.3. Fire counts (counts, in line graph) and burned area (ha, in bar graph) in Thailand, Cambodia, Vietnam and Lao PDR in 2002 for a) forest, and b) paddy fields.

In addition, the January to February period corresponds to a dry wintery season for the region, and so to the period where high pressure and cold air masses from China covers the North and Northeast of Thailand, the north of Cambodia, Lao PDR, and the north of Vietnam. This contributes to a poor dispersion of pollutants emitted from different sources in the atmosphere, and so to an increase in their ambient concentrations including the level of particulate matter, which can exceed the national standards. On the other hand, the dry weather conditions favor a fast propagation of the fires. Therefore, it is recommended to control paddy fields open burning from January to March, in particular in Thailand and Vietnam, the top two countries in rice cultivation of the region.

Amount of straw and stubbles consumed and corresponding energy released by open burning

Results obtained for the 4 countries in the GMS are reported in Table 4 and 5. They are also displayed in GWh in order to investigate their order of magnitude relative to electricity demand in each country.

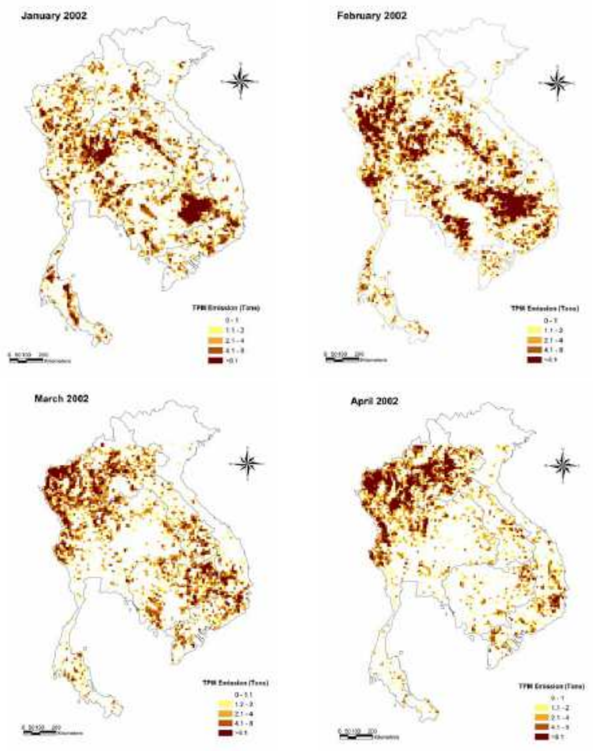

Fig.4. Monthly emission maps of TPM in GMS during January-April 2002.

Table 4. Amount of straw and stubbles and corresponding energy content, RPR = 1.757

Country	Paddy lands (Mha)	Amount of residues (Mt)	Energy content (PJ)	Energy content (GWh)
Cambodia	1.70	5.724	80	22,260
Laos	0.26	1.410	20	5,482
Thailand	10.58	48.499	679	188,607
Vietnam	4.86	39.197	549	152,432

Table 5. Amount of straw and stubbles and corresponding energy content, RPR = 0.750

Country	Paddy lands (Mha)	Amount of residues (Mt)	Energy content (PJ)	Energy content (GWh)
Cambodia	1.70	1.437	34	9,502
Laos	0.26	2.314	8	2,340
Thailand	10.58	1.957	290	80,509
Vietnam	4.86	3.443	234	65,068

Results reported in Table 4 and 5 represent actually the gross amount and energy availability of straw and stubbles. The use of 2 values of RPR enables to frame the range of this gross availability. It resulted from our field survey that the value of 0.750 corresponds to the part of the residues able to be moved out from the fields, and so available for different utilization, while 1.757 represents the whole residue cut few centimeters above the ground. The net amount available for energy production will depend on two other main factors: other utilization and biomass to energy conversion technology in use.

Other significant factors influencing the net availability are the cultivation practices and the level of difficulty to collect, string the straw and stubbles together, and move them out of the fields. It should be noted that the size of paddy fields in the 4 countries of the region studied, is quite small, less than 1 ha in general, compared to the size reported in Europe or USA, and consequently quite difficultly to access by a commercialized tractor. Moreover, the plantation soil is relatively soft, and so the load of a heavy duty tractor would compact the soil, resulting in a hard plowing during the land preparation phase.

4. CONCLUSIONS AND PERSPECTIVES

The emission maps developed in this research work have allowed to easily monitoring seasonal changes of open burning, and the GIS database to identify the type of vegetation that is being burned. These developments have enabled to investigate the spatial and temporal distribution of paddy fields open burning in the GMS for the year 2002.

The results obtained in this study show that Thailand and Vietnam are the two countries, where paddy field open burning occurs most frequently. The peak period of this type of burning runs from January to April, with January and February as the climax period. As this period corresponds to the time when forest fires are the most intense and atmospheric stability is the most stable, i.e. difficult dispersion of air pollutants, it is recommended to control more stringently agricultural open burning to reduce impacts on air quality and therefore support the ASEAN Agreement on Transboundary Haze.

The quantification of gross amount of rice straw and stubbles consumed and corresponding energy released by open burning was helpful in estimating the energy amount that could be recovered from the waste biomass. However, further investigations, especially on updating the RPR values, and on the material flow of straw and stubbles after harvest via field survey in the GMS countries, are needed in order to support the formulation of national action plan of promoting the use of renewable energy resources, and of reducing agricultural open burning.

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