International Renewable Energy Agency

Biofuel Potential in Southeast Asia:

Raising food yields, reducing food waste and utilising residues

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Executive summary

Considerable sustainable resource potential exists for liquid biofuels in Southeast Asia. This report estimates the amounts of feedstocks that could be grown, collected and converted to liquid biofuels in the region. The focus is on lignocellulosic feedstocks that could be grown in an environmentally, socially and economically sustainable fashion, without conflicting with food supplies or causing land use change that could release carbon to the atmosphere and contribute to global warming.

Approaches to expanding biomass feedstocks include more thorough collection of residues from food crops and forest products, as well as planting high-yielding trees and grasses on land made available through more intensive cultivation of farmland (with yields beyond those needed to supply projected food needs) and through reduced waste and losses in the food chain (which can obviate the need to grow food no longer lost or wasted).

Detailed estimates of biomass resource potential are derived for five countries in Southeast Asia which are each both member states of the Association of Southeast Asian Nations (ASEAN) and economies within the Asia Pacific Economic Cooperation (APEC): Indonesia, Malaysia, the Philippines, Thailand and Viet Nam. Both theoretical potential and stretch goals for 2050 are derived for these countries, though the portion of potential that is actually realised will depend on economic, logistical and policy variables.

A survey of bioenergy research, development and demonstration and deployment efforts in these countries also indicates a fair degree of technological readiness for production of advanced biofuels from lignocellulosic feedstocks, despite a relative paucity of advanced biofuel projects in the region. If sustainable biomass feedstock potentials are totalled, assuming conversion to advanced liquid biofuel at typical efficiencies, they could supply up to two-fifths of the region's projected fuel needs for transport in 2050. This potential would be reduced, however, if significant amounts of solid biomass continue to be used for applications outside the transport sector, particularly for residential heating and cooking.

A variety of policies and measures could be implemented to help realise this potential. Farm and forest residue collection could be improved by sharing best practices in cost-effective logistics. Agricultural yields could be improved through extension services to spread modern farming techniques, agroforestry approaches to cultivate a mix of high-yielding food and fuel crops, and more secure land tenure to encourage investment in more intensive land management. Losses and waste in the food chain could be reduced through better harvesting techniques, storage and cooling facilities, packaging and transportation infrastructure to reduce food spoilage on the way from farm to table, as well as better labels and more flexible regulation to ensure that wholesome food is not wasted or discarded. Together, such measures can free up a substantial amount of land to plant with bioenergy crops for biofuel.

Introduction

Substantial resource potential exists to sustainably expand supplies of liquid biofuels in Southeast Asia. Volumes of lignocellulosic feedstocks for biofuels can be expanded through more systematic collection of agricultural residues, as well as through planting of grasses and trees on land made available through more intensive cultivation of croplands and reduced waste and losses in the food chain. If these feedstocks were converted to advanced liquid biofuels using processes that are being demonstrated at commercial scale and becoming increasingly cost-competitive (IRENA, 2016b), advanced liquid biofuels could displace a significant share of petroleum-based transport fuel in the region.

As food production expands to meet the nutritional needs of growing populations, there is also increased production of agricultural residues. If sustainable shares of these residues were fully collected while allowing for residues that are fed to animals for meat and dairy production, substantial amounts would be left over. These could provide fuel for combined heat and power plants, process heat for first-generation biofuel production, or lignocellulosic feedstock for second-generation biofuel processes.

Improving yields through modern agricultural practices, it should also be possible to grow the same amount of food on less land. The freed-up land could be planted with a mix of rapidly growing trees (short rotation coppice) for combined heat and power or second-generation biofuel, high-yielding conventional biofuel crops such as sugar cane, and grasses for lignocellulosic conversion.

Farmland needed for food production could be further reduced by managing the food chain more efficiently and by modifying food consumption habits. About one-third of all food in the region is lost or wasted. If food losses and waste could be reduced or eliminated, obviating the need to grow this food, substantial further amounts of land could be made available for bioenergy and biofuel production.

In addition, forest plantations in Southeast Asia produce wood for construction, furniture and other uses from a wide range of species including acacia, bamboo, coconut palm, eucalyptus, pine, rubber and teak. Part of the wood is left over as a residual for possible conversion to bioenergy.

This paper focuses in particular on five countries in Southeast Asia which are each both member states of the Association of Southeast Asian Nations (ASEAN) and member economies within the Asia Pacific Economic Cooperation (APEC): Indonesia, Malaysia, the Philippines, Thailand and Viet Nam.

Potential for bioenergy from sustainable collection of agricultural residues

For every tonne of crop produced, an amount of residue is available in the field after harvest, of which a fraction can be practically and sustainably collected. This fraction is typically assumed to be between a quarter and a half, so enough residue is left behind to regenerate the soil. In addition, a share of residues is attached to crops when they enter processing plants, most of which can also be collected.[1]

[1] Muth, Bryden and Nelson suggest 2.25 tonnes per hectare (t/ha) of residue can be removed for each crop under 2011 land management practices or 25% of 9.17 t/ha in total residue (weighting residue t/ha for each crop in their Table 5 by crop shares in their Table 7); their Table 6 shows no-till practices raise sustainable collection by 43%, *i.e.* to 35%, by 2030. The World Bioenergy Association asserts that 50% of residue can be sustainably collected. Villamil and Nafziger report that removing 50% or 90% of residue with no-till planting reduces soil carbon and nitrogen stocks by only 6 to 7%.

Multiplying the tonnage of each crop in each country (FAO, 2015) by tonnes of harvest and processing residue per tonne of crop (Smeets, Faaij and Lewandowki, 2004) and assuming an energy content of 15 gigajoules (GJ) per tonne, agricultural residue with an energy content of some 161 exajoules (EJ) was generated worldwide in 2010. Taking 25-50% of harvest residue and 90% of processing residue, 55 EJ-90 EJ could have been used. With projected growth in food supply (Alexandratos and Bruinsma, 2012), assuming that the mix of crops is constant, available agricultural residue could reach 79 EJ-128 EJ globally by 2050.[2] Corresponding amounts of agricultural residue for the five Southeast Asian countries in focus would be 1.73 EJ-2.81 EJ in Indonesia, 0.16 EJ-0.27 EJ in Malaysia, 0.68 EJ-1.07 EJ in the Philippines, 1.22 EJ-1.86 EJ in Thailand, and 0.86 EJ-1.37 EJ in Viet Nam (as shown in column 4 of Tables S-1 and S-2).

Much of this residue, however, would likely be used for animal feed. Dividing the supply of livestock between traditional grazing systems and higher-yield "mixed" systems in each country, and multiplying this by the amount of residue used to produce each tonne of livestock, 19 EJ of residue is seen to have been used for feed in 2010. With projected growth in demand for livestock for milk and meat consumption (Alexandratos and Bruinsma, 2012)[3], 33 EJ of residue could go to feed by 2050, leaving 46 EJ-95 EJ to use for biofuel. For Southeast Asia, net available residue for biofuel would be 1.43 EJ-2.50 EJ in Indonesia, 0.08 EJ-0.18 EJ in Malaysia, 0.38 EJ-0.77 EJ in Philippines, 0.99 EJ-1.63 EJ in Thailand, and 0.43 EJ-0.94 EJ in Viet Nam (as shown in petajoules (PJ) in column 6 of Tables S-1 and S-2).

Table S-1 Residue potential for 2050 (PJ/year) – 25% collection of harvest residue

Country	Harvest Residue	Process Residue	Total Residue	Residue for Feed	Residue for Fuel	40% to Biofuel (Energy Content)	Share of Liquid Fuel Use in 2012
Indonesia	1 079	653	1 732	306	**1 426**	**570**	**31%**
Malaysia	104	59	163	87	**76**	**30**	**5%**
Philippines	393	288	680	303	**377**	**151**	**44%**
Thailand	641	578	1 220	226	**993**	**397**	**51%**
Viet Nam	508	353	861	426	**435**	**174**	**37%**
WORLD	49 278	29 730	79 008	32 877	46 131	18 452	19%

IRENA analysis (Appendix I)

[2] Projected yearly growth in food supply is globally 1.3% through 2030 (ranging from 0.8% in developed countries to 2.4% in Sub-Saharan Africa) and 0.7% from 2030 through 2050 (ranging from 0.3% to 1.9%).

[3] Projected annual growth in meat consumption is globally 1.4% through 2030 (from 0.6% in developed countries to 2.7% in Sub-Saharan Africa) and 0.9% from 2030 to 2050 (from 0.2% to 2.6%).

Table S-2 Residue potential for 2050 (PJ/year) – 50% collection of harvest residue

Country	Harvest Residue	Process Residue	Total Residue	Residue for Feed	Residue for Fuel (Primary Biomass)	40% to Biofuel (Energy Content)	Share of Liquid Fuel Use in 2012
Indonesia	2 158	653	2 811	306	2 505	1 002	55%
Malaysia	208	59	267	87	179	72	12%
Philippines	785	288	1 073	303	770	308	91%
Thailand	1 282	578	1 861	226	1 635	654	84%
Viet Nam	1 015	353	1 368	426	942	377	79%
WORLD	98 555	29 730	128 285	32 877	95 409	38 163	39%

IRENA analysis (Appendix I)

At a 40% conversion efficiency in a lignocellulosic process, this residue would yield 18 EJ-38 EJ of biofuel globally. That is roughly one-fifth to two-fifths of all the liquid fuel that was used for transport in 2012, and potentially much more than the 22 EJ of fuel used for marine shipping and aviation (IEA, 2012).[4] In Southeast Asia, advanced biofuel from residues could displace the bulk of all fuel use for transport in the Philippines, Thailand and Vietnam and about half of all fuel use for transport in Indonesia.

Potential for bioenergy through sustainable intensification of agriculture (higher crop yields)

Growth in yields per hectare is responsible for some 80% of the increase in food production and residue potential implicit in projections by the United Nations Food and Agriculture Organisation (FAO). Another 10% is due to planting multiple crops on the same land each year. Only 10% of projected increased food production comes from expanding arable land (Alexandratos and Bruinsma, 2012). But yields could grow faster if greater efforts were made to expand extension services and financial supports so that farmers in countries with lower crop yields could adopt and adapt the practices that produce higher yields elsewhere, as appropriate to their circumstances. With higher yields, less land would be needed for food and more could be used for biofuel feedstock.

FAO projects that global average crop yield will rise from 4.2 tonnes per hectare (t/ha) in 2010 to 5.1 t/ha in 2050. But applying the trend in yield growth by crop from 1961 through 2013, the average could reach 6.6 t/ha by 2050 (FAO, 2015). While 1 079 million hectares (Mha) would have to be planted in 2050 to meet world food needs at projected yields, just 839 Mha would be needed at the higher yields, freeing 240 Mha for biofuel crops.

FAO has also assessed the gap between current and potential crop yields, assuming the current mix of irrigated and "rain-fed" land. Globally, the average gap is 62.1 t/ha for sugars, 3.9 t/ha for cereals, 12.7 t/ha for root crops and 0.6 t/ha for oil crops (FAO, 2015). For each country, taking the land to meet food demand with current yields for each crop type and dividing by the ratio of actual to potential yield, IRENA calculated the land that would be required to meet food needs if the yield gap were closed.

[4] Data for 2012 indicate 2.17 EJ for domestic navigation, 7.91 EJ for marine bunkers, 4.12 EJ for domestic aviation and 6.75 EJ for aviation bunkers, or a total of 21.95 EJ for marine and aviation use.

To close the gap would entail raising average global crop yield to 10.4 t/ha in 2050 so that only 527 Mha would be needed for food, rather than the 1 079 Mha projected by the FAO, leaving 552 Mha for biofuel crops. If this land were planted with grasses yielding 150 GJ per hectare (GJ/ha), it could produce 83 EJ of biomass. Converted at 40% efficiency, this would yield 33 EJ of biofuel, about one-third of current transport fuel use (IRENA, 2016a).

In Southeast Asia, closing the yield gap could make enough land available for advanced biofuels to displace 14% of current liquid transport fuel use in Indonesia, 13% in Malaysia, 27% in Thailand, 37% in Viet Nam and a proportionally much larger 122% in the Philippines (Tables S-3 and Y-1-5).

Table S-3 Biomass potential from higher yields in 2050 – yield gap closure case

Country	Land Freed (M ha)	Biomass Potential 150 GJ/ha (PJ/year)	40% to Advanced Biofuel (PJ/year)	Liquid Transport Fuel Use 2012 (PJ)	Potential Share of 2012 Fuel Use
Indonesia	4.26	638	255	**1 822**	**14%**
Malaysia	1.27	190	76	**596**	**13%**
Philippines	6.87	1 031	412	**339**	**122%**
Thailand	3.45	518	207	**780**	**27%**
Viet Nam	2.91	436	174	**475**	**37%**
WORLD	551.71	82 757	33 103	97 456	34%

IRENA analysis (Appendix II)

Potential for bioenergy on land freed by reducing wastes and losses in the food chain

Large amounts of food are lost in production and distribution or wasted at the point of consumption. The FAO has found that one-third of food produced for human consumption is lost or wasted globally, amounting to 1.3 billion tonnes per year. Production and distribution losses have similar proportions in developed and developing countries, amounting to 31-33% in Europe and North America (280 kg-300 kg out of 900 kg of food produced per capita per year) and 26-37% in Sub-Saharan Africa and South/ Southeast Asia (120 kg-170 kg out of 460 kg of food produced per capita per year). But consumer food waste is higher in developed countries (11-13%) than developing ones (1-2%) (Gustavsson *et al.*, 2011).

For each major region and food group, FAO data show percentage losses in agricultural production, postharvest handling and storage, processing and packaging, retail distribution, and consumption (Gustavsson *et al.*, 2011). From these, the total percentage and tonnage lost or wasted for each food group can be calculated. For crops directly consumed, tonnes lost or wasted can be divided by average yield in tonnes per hectare to find how many hectares could be liberated by eliminating the losses and waste. For meat and dairy products, one may calculate the amounts of different kinds of feed to produce each, then the area used to produce the feed, and finally (multiplying this area by the share of product lost) the land spared.

Table S-4 Shares of food production lost at different food chain stages in South and Southeast Asia

Food Group	Total Loss All Stages Combined	Agricultural Production	Postharvest Handling and Storage	Processing and Packaging	Distribution: Supermarket Retail	Consumption
Cereals	21%	6%	7%	3.5%	2%	3%
Roots and tubers	43%	6%	19%	8%	8%	2%
Oilseeds, pulses	29%	8%	12%	7%	2%	1%
Fruit, vegetables	61%	18%	9%	23%	7%	4%
Meat	21%	5.1%	0.3%	5%	7%	4%
Fish and seafood	38%	9%	6%	8%	13%	1%
Milk	22%	3.5%	6%	2%	9%	1%
All (except fish and seafood)	32%	8%	11%	8%	3%	2%

Source: Gustavsson *et al.* (2011)

Globally, 442 Mha of land could be freed up in 2050 by eliminating losses and waste for crops directly consumed as food, and another 340 Mha freed up by eliminating losses and waste of meat and dairy products. With 782 Mha liberated in all, biofuel crops yielding 150 GJ/ha would provide 117 EJ of biomass, converting at 40% efficiency to 47 EJ of advanced biofuel. If the yield gap were closed, land freed by eliminating losses would decline to 553 Mha, biomass potential to 83 EJ and advanced biofuel potential to 33 EJ – still enough to displace one-third of current liquid transport fuel (IRENA, 2016a).

In Southeast Asia, potential land freed and corresponding biomass potential in 2050 are as follows, assuming yield per hectare increases as projected by the FAO and that the bioenergy crops planted on the land that is liberated result in typical yields of 150 GJ/ha:

Table S-5 Potential land freed by reduced food waste in 2050 – FAO case (k ha)

Country	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Indonesia	13 792	3 716	3 619	3 162	1 973	1 323
Malaysia	3 608	943	827	869	629	339
Philippines	9 944	2 688	1 502	2 511	2 031	1 212
Thailand	8 306	2 269	1 775	1 935	1 376	951
Viet Nam	8 420	2 247	1 128	1 918	1 949	1 179

IRENA analysis (Appendix III)

Table S-6 Biomass potential on land freed by reduced food waste 2050 – FAO case (PJ)

Country	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Indonesia	2 069	557	543	474	296	198
Malaysia	541	141	124	130	94	51
Philippines	1 492	403	225	377	305	182
Thailand	1 246	340	266	290	206	143
Viet Nam	1 263	337	169	288	292	177

IRENA analysis (Appendix III)

If yields were to rise beyond what FAO projects, so that lost or wasted food were produced on less land, reduced waste and losses would cause less land to be liberated, as follows:

Table S-7 Potential land freed by reduced food waste in 2050 – yield gap closure (k ha)

Country	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Indonesia	10 970	2 961	2 678	2 584	1 660	1 087
Malaysia	2 801	731	618	683	503	267
Philippines	6 804	1 847	866	1 848	1 422	822
Thailand	5 661	1 506	1 069	1 467	1 010	609
Viet Nam	6 412	1 718	691	1 516	1 563	924

IRENA analysis (Appendix III)

Table S-8 Biomass potential on land freed by reduced food waste, 2050 – yield gap closure (PJ)

Country	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Indonesia	1 645	444	402	388	249	163
Malaysia	420	110	93	102	75	40
Philippines	1 021	277	130	277	213	123
Thailand	849	226	160	220	151	91
Viet Nam	962	258	104	227	234	139

IRENA analysis (Appendix III)

It is interesting to consider the portion of this potential that might be obtained by the implementation of global best practice, as indicated by the region with the lowest share of waste or loss for each food group at each stage of the food chain (Table S-9).

The South and Southeast Asia region is operating at or near regional best practice for milk production losses, post-harvest handling losses of meat, processing losses of meat and cereals, cereal distribution losses, and consumption waste of fruit and vegetables.

Table S-9 Shares of food production lost at different food chain stages – global best practice

Food Group	Agricultural Production	Postharvest Handling and Storage	Processing and Packaging	Distribution: Supermarket Retail	Consumption
Cereals	2%	2%	3.5%	2%	1%
Roots and tubers	6%	7%	10%	3%	2%
Oilseeds and pulses	6%	0%	5%	1%	1%
Fruit and vegetables	10%	4%	2%	8%	5%
Meat	2.9%	0.2%	5%	4%	2%
Milk	3.5%	0.5%	0.1%	0.5%	0.1%

Source: Gustavsson *et al.* (2011)

With waste and losses reduced to best practice levels, roughly half of the potential for biomass is obtained:

Table S-10 Biomass potential on land freed by food chain best practice – yield gap closure (PJ)

Country	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Indonesia	774	185	326	113	79	70
Malaysia	189	34	88	21	31	15
Philippines	441	116	93	112	70	49
Thailand	382	97	111	92	47	36
Viet Nam	383	122	71	35	88	67

IRENA analysis (Appendix III)

In the Southeast Asian countries studied, with 40% efficient lignocellulosic conversion, the potential for advanced biofuel on land freed by reduced food waste could approach or exceed transport fuel use in 2012, assuming FAO projections for crop yields. With the yield gap closed and all regions adopting regional best practices in food waste reduction, the shares would be one-third as great (Table S-11).

Table S-11 Potential displacement of transport fuel by reduced food waste and losses

Country	Liquid Transport Fuel Use 2012 (PJ)	Biofuel Potential from Reduced Food Waste - FAO Yields (Share of 2012 Fuel)	Biofuel Potential from Reduced Food Waste – No Yield Gap (Share of 2012 Transport Fuel)	Biofuel Potential of Best Practice Food Waste Reduction – No Yield Gap (Share of 2012 Fuel Use)
Indonesia	1 822	2 069 PJ (114%)	1 645 PJ (90%)	774 PJ (42%)
Malaysia	596	541 PJ (91%)	420 PJ (70%)	189 PJ (32%)
Philippines	339	1 492 PJ (440%)	1 021 PJ (301%)	441 PJ (130%)
Thailand	780	1 246 PJ (160%)	849 PJ (109%)	382 PJ (49%)
Viet Nam	475	1 263 PJ (266%)	962 PJ (203%)	383 PJ (81%)

Potential for bioenergy from productive forests

There is significant potential for energy wood from productive forests, which is available for use in combined heat and power plants today but could also be converted to biofuel in advanced biorefineries. Globally, productive forests might provide a further 27 EJ per year (Cornelissen, Koper and Deng, 2012). As shown in Appendix IV, a wide variety of wood species are grown. Assuming a steady state in the plantations, a certain volume of biomass is produced each year and can be extracted without affecting the overall amount of wooden biomass that remains in the forest. Of the amount extracted, a certain share is lumber for buildings, furniture and other uses that continue to store carbon for many years – typically decades. The rest is available for conversion to energy – biofuel or combined heat and power.

The division between lumber and energy wood depends on the density and durability of the species. The wide variety of wood species may be roughly classified, as in Appendix IV, into three categories:

- Process woods, suitable for lumber, may provide around 40% of their content for energy wood. Some part of the tree trunk volume can be sawn into lumber, and the other part of the wood is typically in large enough pieces to be used for furniture or other objects. Some of the best-known woods in this category, grown in the largest quantities, are rubber, coconut palm and teak.[5]
- Fibrous woods, such as acacia and eucalyptus, are well suited to pulp and paper production. About 20% of such woods typically become available as a residual that might be used for energy.[6]
- Some grass species, such as bamboo, are also important to consider. Their processed materials are well suited to building construction and furniture manufacture. Their entire cross-section can be used for such purposes, and softer parts of the plant are commonly also used for animal fodder, so in mature markets, only about 15% is left over as a processing residual for potential energy use.[7]

The yearly bioenergy potential from these and other species can be estimated by a simple procedure:

1) Multiply annual growth (cubic metres per hectare per year – m^3/ha/yr) by density (tonnes per cubic metre – t/m^3) to find ***wood growth per hectare*** (tonnes per hectare per year – t/ha/yr).
2) Multiply by thousand hectares planted to calculate ***total extractable wood*** in tonnes per year.
3) Multiply by wood energy share to calculate ***energy wood*** in tonnes per year.
4) Multiply by an average of 19 GJ energy per tonne[8] to calculate ***energy potential*** in PJ per year.

The results of this procedure are summarised in Table S-12 for all species or genera (groups of species) with over a million hectares of area planted in the five countries studied (Appendix IV, Table F-5 may be consulted for a more complete accounting, also including other species planted in lesser quantities). In descending order by land planted, these include: rubber (6.8 Mha), coconut palm (5.6 Mha), bamboo (4.0 Mha), acacia (2.8 Mha), teak (2.2 Mha), pine (1.6 Mha) and eucalyptus (1.2 Mha). In terms of aggregate energy potential, the most important woods for the five countries studied are: rubber (409 PJ), acacia (174 PJ), coconut palm (83 PJ), teak (69 PJ) and pine (44 PJ). The different rankings result from different intensities of yield per hectare and different shares of energy wood in total wood.

[5] Rayn (1999), cited in FAO (2001), reports from a survey in Malaysia that sawmills recovered 52% and plywood mills 49% of primary teak harvest for lumber. FAO (2001) also reports that a survey in Indonesia estimates residue from secondary processing, which would be used for other products, as 10% of the primary processing volume.

[6] PT. Bina Silva Nusa (2016), an Indonesian wood chip producer certified by the Forest Stewardship Council (FSC), cites 20% as residues from chip production. MAFF (2011) reports that 23% of wood chip production in Japan goes to power, heating and other applications, while 60% goes to paper, 6% to wood board and 1% to fodder.

[7] INBAR (2016) suggests that in places like China and India, with well-developed value chains for multiple products, 8-15% of bamboo might be left over for energy use. In countries with less developed value chains, however, a larger share of bamboo might be available for energy as markets for higher-value-added bamboo products evolve.

[8] The Biomass Energy Centre (n.d.) notes energy content of 19.0 GJ/t at 0% moisture.

Table S-12 Energy potential of Southeast Asia forest species planted on over a million hectares

Species	Productive Forest Area (Thousand Hectares)	Total Wood (Thousand Tonnes Per Year)	Energy Wood (Thousand Tonnes Per Year)	Energy Potential (Petajoules Per Year)
Acacia mangium and other (Acacia)	2 757	45 709	9 141	174
Bambusae (Bamboo)	4 004	4 905	736	14
Cocos nucifera (Coconut palm)	5 625	10 874	4 350	83
Eucalyptus grandis and other (Eucalyptus)	1 177	8 894	1 778	34
Hevea brasiliensis (Rubber)	6 773	53 845	21 538	409
Pinus merkusii and other (Pine)	1 578	8 683	2.324	44
Tectona grandis (Teak)	2 163	9 084	3 634	69
Total (all species)	**26 169**	**155 592**	**47 502**	**903**

IRENA analysis (Appendix IV)

Table S-13 shows forest hectares planted, resulting annual wood yield, energy wood increment and associated energy potential by country, for all species combined.

Table S-13 Calculated energy potential of forest species by country

Country	Productive Forest Area (Thousand Hectares)	Total Wood (Thousand Tonnes Per Year)	Energy Wood (Thousand Tonnes Per Year)	Energy Potential (Petajoules Per Year)
Indonesia	11 470	63 475	20 786	395
Malaysia	3 644	38 685	9 845	187
Philippines	2 900	8 103	2 909	55
Thailand	5 014	30 602	10 058	191
Viet Nam	3 141	14 457	3 904	74
TOTAL	**26 169**	**155 592**	**47 502**	**903**

IRENA analysis (Appendix IV)

Table S-14 shows the potential impact of advanced biofuels from forests as a share of current fuel use.

Table S-14 Biofuel potential from planted forests as share of liquid fuel use

Country	Energy Potential (PJ/year)	Advanced Biofuel Potential at 40% Efficiency (PJ/year)	Liquid Transport Fuel Use 2012 (PJ)	Potential Share of 2012 Fuel Use
Indonesia	395	158	1822	9%
Malaysia	187	75	596	13%
Philippines	55	22	339	5%
Thailand	191	76	780	6%
Viet Nam	74	30	475	6%

Energy security implications and possible policy options

Globally, analysis indicates sustainable potential for up to 288 EJ of primary biomass. This comes from residues (95 EJ), land freed by closing the yield gap (83 EJ), land freed by eliminating waste and losses in the food chain (83 EJ) and trees in forest land (27 EJ). This could provide up to 230 EJ of liquid biofuel in a first-generation conversion process, 230 EJ of conventional heat and electricity, or 115 EJ of drop in diesel fuel for jets, ships and trucks in a second-generation conversion process to produce drop-in diesel fuel for jets, ships and trucks. This would exceed the total liquid fuel use for transport worldwide in 2012. Additional biomass could come from more efficient use of pasture, degraded land and forest residues.

In Southeast Asia, the potential for reducing fossil fuel reliance is also great:

- Table S-15 sums up the four main categories surveyed, assuming that 50% of harvest residues are collected, the yield gap is completely closed, waste and losses in the food chain are completely eliminated, and the full increment of forest biomass is collected. This may be regarded as the long-run theoretical potential.
- Table S-16 sums up the same three categories, assuming that 25% of harvest residues are collected, the yield gap is half closed, all regions reduce waste and losses in the food chain to the shares in each food group that obtain in the region with best practice, and half of the forest potential is collected. This may be seen as a “stretch goal” to be pursued within a broad time horizon, such as 2050.
- Table S-17 compares the advanced biofuel potential to current and projected liquid transport fuel demand.[9]

[9] The International Energy Agency (IEA) (2015) indicates annual growth of ASEAN transport fuel demand of 2.68% in 2012-20, 1.89% in 2020-30, and 0.99% in 2030-40. Projections for 2050 apply these growth rates, extending the 2030-40 rate through 2050.

Table S-15 Advanced biofuel potential from residues, higher yields, reduced waste and forests

Country	Residues Potential with 50% Collection (PJ/year)	Potential from Closing Yield Gap (PJ/year)	Potential from Reduced Waste If Yield Gap Is Closed (PJ/year)	Forest Energy Wood Potential (PJ/year)	Total Primary Energy Potential (PJ/year)	Converted 40% to Advanced Biofuel (PJ/year)
Indonesia	2 505	638	1 645	395	5 183	2 073
Malaysia	179	190	420	187	976	390
Philippines	770	1 031	1 021	55	2 877	1 151
Thailand	1 635	518	849	191	3 193	1 277
Viet Nam	942	436	962	74	2 414	966
REGION	6 031	2 813	4 897	903	14 644	5 858

Table S-16 Goals for advanced biofuel from residues, higher yields, reduced waste and forests

Country	Residues Potential with 25% Collection (PJ/year)	Potential Closing Half the Yield Gap (PJ/year)	Potential from Reduced Waste Best Practice If Yield Gap Closed (PJ/year)	Half the Forest Wood Potential (PJ/year)	Total Primary Energy Potential (PJ/year)	Converted 40% to Advanced Biofuel (PJ/year)
Indonesia	1 426	319	774	198	2 717	1 087
Malaysia	76	85	189	94	444	178
Philippines	377	515	441	28	1 361	544
Thailand	993	259	382	95	1 729	692
Viet Nam	435	218	383	37	1 073	429
REGION	3 307	1 396	2 169	452	7 324	2 930

Table S-17 Stretch goals for advanced biofuel as share of projected liquid transport fuel use

Country	Converted 40% to Advanced Biofuel (PJ/year)	Liquid Transport Fuel Use 2012 (PJ)	Biofuel Share of 2012 Transport Fuel Use	Liquid Transport Fuel Use 2050 (PJ)	Biofuel Share of 2050 Transport Fuel Use
Indonesia	1 087	1 822	55%	3 308	33%
Malaysia	178	596	23%	1 082	16%
Philippines	544	339	157%	615	88%
Thailand	692	780	84%	1 417	49%
Viet Nam	429	475	87%	862	50%
REGION	2 930	4 013	73%	7 264	40%

Source: IEA/OECD (2016) and IRENA analysis

Looking at a stretch goal for 2050, as indicated in Table S-17, advanced biofuels could displace around one-sixth of projected fuel use in Malaysia, one-third in Indonesia, one-half in Thailand and Viet Nam, and nearly all in the Philippines. For the five-country group, such biofuels might displace two-fifths of projected liquid transport fuel use. In view of the large potential, it is useful to consider what portion might practically be realised and what policies and measures would hold the most promise for developing the potential and bringing it to market.

In fact, the amount of solid biomass available for the transport sector will depend on the amount used in other sectors, particularly for residential heating and cooking. In the five countries studied, primary solid biomass use amounted to 3 718 petajoules (PJ) in 2000 and 4 456 PJ in 2014 (IEA/OECD, 2016). Extrapolating the 1.3% annual growth trend, primary solid biomass use outside the transport sector would reach 7 097 PJ by 2050 and draw down almost the entire lignocellulosic resource stretch goal calculated. However, traditional wood stoves are being replaced by modern stoves that mainly use liquefied petroleum gas (LPG) in Indonesia, which accounts for over half the current and extrapolated use (ASTAE, 2013).[10]

Both cooking and heating might be electrified as Southeast Asian economies develop, and a growing share of electricity might be provided by renewable solar, wind and geothermal power resources. With strong policies to promote renewable electricity, including fair compensation for the marginal costs avoided by reduced generation of electricity from fossil fuels, as well as LPG, the use of solid biomass in homes could decline substantially, leaving most of the biomass available for advanced liquid biofuels.

Several courses of action could help to raise agricultural yields in Southeast Asia, which is key to raising supplies of residues and to freeing land for bioenergy crops. Capacity building and extension services could be expanded to spread modern farming techniques in rural areas. Best practices on logistical approaches for cost-effective harvesting of farm and forest residues could be compiled and disseminated. Agroforestry strategies for investing in cultivation of a mix of high-yielding food and fuel crops could be developed from successful experiences with stakeholders in the countries. More secure land tenure and more effective land governance can provide the financial incentives that are needed for long-term investment in intensive, sustainable land management.

A variety of policies and measures could also help to reduce food losses and waste. In rural areas of Southeast Asia, improved harvesting techniques, storage and cooling facilities and better packaging can reduce food spoilage, while expanded transportation infrastructure can bring more food to market while it remains fresh and saleable. Extension services and capacity building could help improve harvesting techniques, local health regulations could require better packaging and development assistance could help build better infrastructure. In urban areas, waste can be reduced by differentiating prices to encourage sale of food items that are not perfect in shape or appearance, modifying labels so that "best-before" dates do not encourage consumers to discard food prematurely and raising awareness of possible uses for safe food that is thrown away. Regulations to allow sale of lower quality food items that meet health guidelines, engagement by food distributors and retailers to make food labels more informative and advertising to change consumers' attitudes can also be helpful (Gustavsson *et al.*, 2011).

[10] Of 85 million Indonesian households in 2050, 72 million would cook with LPG, 7 million with modern wood stoves, 3 million with electric stoves, 2 million with kerosene, 1 million with charcoal and virtually none with traditional wood stoves.

Points of departure for the development of advanced biofuel resources in Southeast Asia

While awaiting the development of cost-effective options for conversion of lignocellulosic feedstocks into advanced biofuels, the countries of Southeast Asia have been developing such feedstocks for use in combined heat and power applications. These are apt to be the feedstocks that the countries initially draw upon for conversion to advanced biofuels when the processes are deemed cost-effective.

Indonesia is a leading producer of first-generation biodiesel from palm oil plantations, from which empty fruit bunches and shells could someday serve as a key feedstock for advanced biodiesel production. Power is already being produced from such palm oil residues (a 10-megawatt (MW) plant in Riau) as well as from rice husks (a 3-MW plant in Lampung), with these other potential feedstocks for advanced biofuel (Kumar *et al.*, 2010). There is also substantial lumber production in Sumatra and Kalimantan, with which some 5 million cubic meters per annum of residues (as stems, stumps, branches and twigs, and chipped wood) are associated. Rapidly growing tree species in managed forests might serve as additional feedstock (Tambunan and Simangnsong, 2015).

Malaysia is also a major producer of biodiesel from palm, and lignocellulosic feedstocks from the country's palm plantations could likewise serve as a logical feedstock for advanced biofuel production.

The Philippines have several bioethanol production facilities using sugarcane or molasses as feedstock, as well as biodiesel plants based on esterification of coconut oil (Yamaguchi, 2013). The country has a major agricultural sector from which residues could be utilised for more advanced biofuels. Perhaps sugarcane bagasse or coconut residues would be logical initial feedstocks for such development.

Thailand has devoted considerable attention to studying the potential for energy production from agricultural residues, which are extensively used for electricity generation. By the end of 2008, some 2 225 MW of biomass-fired generating capacity was in service, from which 91% of the electricity was generated from sugarcane bagasse, rice husks or wood (Kumar *et al.*, 2010). The Department of Alternate Energy Development and Efficiency at Thailand's Ministry of Energy has estimated that biomass could potentially provide 4 400 MW of generating capacity. Alternatively, a portion of the residues could be converted to advanced biofuels (Kumar *et al.*, 2013).

In Viet Nam, the main crops yielding significant quantities of agricultural residues are paddy rice, sugar cane and maize, with much smaller amounts of cassava, cotton, peanuts and soy. There is also a significant area of managed forest that could be drawn upon (Nguyen and Tran, 2015).

Technical readiness for advanced biofuel conversion in Southeast Asia

In evaluating the prospects for advanced biofuel markets in Southeast Asia, it is interesting to consider the technical readiness of countries to make use of advanced biofuel conversion processes once they have been shown to be cost-effective.

Ideally, there would be direct experience with processes for conversion of lignocellulosic feedstocks such as wood and agricultural residues to biofuel. Yet also of value, from the viewpoint of technical readiness, is experience with other biofuel conversion processes.

Indonesia and Malaysia are the two largest palm oil producers in the world. Some 10 million oil palm trunks in Indonesia and 27 million in Malaysia are left behind on plantations when the trees become less productive after 20-25 years, resulting in substantial emissions of methane, a powerful greenhouse gas. The number of oil palm trunks may quintuple to 50 million by 2030 in Indonesia. A significant volume of ethanol, averaging 60 litres per trunk, is expected to be produced by a fermentation technology using sap from such oil palm trunks, mitigating the emissions (Kosugi *et al.*, 2010).

Indonesian universities and research institutions have undertaken projects to convert a variety of feedstocks to ethanol and biodiesel. Hydrolysis and fermentation have been used to produce ethanol from empty palm fruit bunches, banana skins and stems, corn stalks, papaya bark, pineapple skin, algae and fungi. Biodiesel has been widely produced from conventional crude palm oil, but research has also focused on trans-esterification of nyamplung (*Calopyllum inophyllum*), a plant rich in oil; ultrafiltration of micro-algae; and (at the Indonesian Institute of Sciences) lignocellulose (Yamaguchi, 2013).

Malaysia has substantial experience in upgrading palm oil to standardised biodiesel that can meet international performance standards. This could serve as an important basis for understanding advanced processes to produce biodiesel or ethanol from lignin and cellulose.

The Philippines have somewhat similar experience in producing useable biodiesel from coconut oil. The country has also made some efforts to explore alternative oil-based feedstocks like jatropha and a local tree called petroleum nut (*Pittosporum resineferum*). Whether these imply a sufficient technical basis for proceeding to second-generation processes, should they prove cost-competitive, is unclear (Yamaguchi, 2013). An innovative technology to produce cellulosic ethanol efficiently using sugar cane stalk, leaf and bagasse is being demonstrated in a plant producing 100 kilotonnes (kt) per year in the Philippines (Ishibashi, 2016).

Thailand would appear to have a high level of technical readiness for advanced biofuel conversion. A variety of relevant research projects have been undertaken by the National Science and Technology Development Agency (catalysts), Thailand Institute of Scientific and Technological Research (biofuel production techniques) and King Mongkut's University of Technology - KMUTT (bio-oil reforming). These institutions have directly supported work on second-generation technologies for cellulosic ethanol (Yamaguchi, 2103). A facility producing ethanol from molasses, using a first-generation technology, has started producing 10 kilolitres per day (kL/day) also from bagasse (120 kL/day of capacity), through a second-generation process (Kumar *et al.*, 2013). Together with the Japan International Research Center for Agricultural Sciences (JIRCAS), KMUTT has developed a Biological Simultaneous Enzyme Production and Saccharification (BSES) method that requires no addition of cellulosic enzymes for saccharification. This reduces costs and boosts yields for the production of ethanol from cellulosic biomass, such as cassava pulp, bagasse, corn stem and leaf, oil palm trunk, paper waste, and erianthus, among others (Kosugi, 2016). A demonstration plant to produce 700 kL/year of ethanol from sugarcane bagasse using polymetric membranes has also begun operation (Furukawa, 2016).

In Viet Nam, an advanced biofuels research project at laboratory scale has focused on production of ethanol from rice straw. Another project has used a two-stage process to produce biodiesel from jatropha, with esterification to concentrate the free fatty acids and transesterification to generate fatty acid methyl esters (FAME). Yet another project has produced biodiesel from marine microalgae. There is also research to investigate the potential of microorganisms to digest lignocellulosic feedstocks (Nguyen and Tran, 2015).

By and large, the countries in Southeast Asia have considerable technical background to enable advanced biofuels production. Technical capabilities in the region should also progress as technologies for producing biofuels from lignocellulosic feedstocks are being demonstrated elsewhere. Meanwhile, the region can use the considerable biomass resources from its farms and forests to supply heat and power, as well as transport fuels if desired, from the conventional plants and refining processes already available.

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Appendix I: Bioenergy potential from agricultural residues in Southeast Asia

Table R-1 Residue potential for biofuel – summary table

The residue available for conversion to fuel in each country is calculated as the difference between the total residue and the residue required for animal feed. Total residue adds harvest residue and process residue. Calculations in tonnes, in tables that follow, are converted to energy terms assuming 15 GJ energy per tonne.

Residue potential for biofuel with 25% of harvest residue collected

Available residue is calculated for 2010 (Table R-1a) and projected to 2030 and 2050 (Tables R-1b, R-1c).

Table R-1a Residue potential for 2010 (PJ/year) – 25% collection of harvest residue

Country	Harvest Residue	Process Residue	Total Residue	Residue for Feed	Residue for Fuel
Indonesia	816	494	1 311	205	**1 106**
Malaysia	77	44	121	60	**60**
Philippines	297	218	515	193	**322**
Thailand	476	429	905	160	**745**
Viet Nam	384	267	651	270	**381**
WORLD	34 341	20 838	55 179	19 440	35 739

Table R-1b Residue potential for 2030 (PJ/year) – 25% collection of harvest residue

Country	Harvest Residue	Process Residue	Total Residue	Residue for Feed	Residue for Fuel
Indonesia	1 016	615	1 631	261	**1 370**
Malaysia	96	54	150	70	**80**
Philippines	370	271	641	259	**382**
Thailand	592	534	1 126	182	**944**
Viet Nam	478	333	811	363	**447**
WORLD	43 914	26 597	70 510	25 155	45 355

Table R-1c Residue potential for 2050 (PJ/year) – 25% collection of harvest residue

Country	Harvest Residue	Process Residue	Total Residue	Residue for Feed	Residue for Fuel
Indonesia	1 079	653	1 732	306	**1 426**
Malaysia	104	59	163	87	**76**
Philippines	393	288	680	303	**377**
Thailand	641	578	1 220	226	**993**
Viet Nam	508	353	861	426	**435**
WORLD	49 278	29 730	79 008	32 877	46 131

Residue potential for biofuel with 50% of harvest residue collected

Available residue is calculated for 2010 (Table R-1d) and projected to 2030 and 2050 (Tables R-1e, R-1f).

Table R-1d Residue potential for 2010 (PJ/year) – 50% collection of harvest residue

Country	Harvest Residue	Process Residue	Total Residue	Residue for Feed	Residue for Fuel
Indonesia	1 633	494	2 127	205	1 922
Malaysia	154	44	198	60	137
Philippines	594	218	812	193	619
Thailand	951	429	1 380	160	1 220
Viet Nam	768	267	1 035	270	766
WORLD	68 681	20 838	89 519	19 440	70 079

Table R-1e Residue potential for 2030 (PJ/year) – 50% collection of harvest residue

Country	Harvest Residue	Process Residue	Total Residue	Residue for Feed	Residue for Fuel
Indonesia	2 032	615	2 648	261	2 386
Malaysia	192	54	246	70	176
Philippines	740	271	1 011	259	752
Thailand	1 184	534	1 718	182	1 536
Viet Nam	956	333	1 289	363	926
WORLD	87 828	26 597	114 424	25 155	89 269

Table R-1f Residue potential for 2050 (PJ/year) – 50% collection of harvest residue

Country	Harvest Residue	Process Residue	Total Residue	Residue for Feed	Residue for Fuel
Indonesia	2 158	653	2 811	306	2 505
Malaysia	208	59	267	87	179
Philippines	785	288	1 073	303	770
Thailand	1 282	578	1 861	226	1 635
Viet Nam	1 015	353	1 368	426	942
WORLD	98 555	29 730	128 285	32 877	95 409

Table R-2 Crop production by type and country in 2010

The starting point for calculating the amounts of residue in each country is to tabulate the amounts of each crop that are grown in 2010, which can later be multiplied by amounts of residue per tonne of crop.

Crop (Thousand Metric Tonnes)	Indonesia	Malaysia	Philippines	Thailand	Viet Nam
Agave fibres not elsewhere specified			4		
Anise, badian, fennel, coriander					4
Areca nuts	181	1		38	
Asparagus			5	63	
Avocados	253		22		
Bananas	6 087	316	9 093	1 571	1 480
Barley				20	
Bast fibres, other	4			3	
Beans, dry	316		29	101	192
Beans, green	904		19	303	
Berries not elsewhere specified					143
Cabbages and other brassicas	1 369	116	126	512	775
Canary seed				34	
Carrots and turnips	430		69		
Cashew nuts, with shell	138	14	127	35	1 215
Cassava	23 322	48	2 118	24 669	9 008
Castor oil seed	2		0	12	6
Cauliflowers and broccoli	104		11	41	30
Cereals not elsewhere specified				205	
Chicory roots			4		
Chillies and peppers, dry		2		155	89
Chillies and peppers, green	1 398	31	21	18	
Cinnamon (canella)	96				20
Cloves	85	0			
Cocoa, beans	789	18	5	1	
Coconuts	18 167	529	15 474	1 245	1 164
Coffee, green	667	16	93	49	1 147
Coir		20		60	282
Cotton lint	1		0	3	4
Cottonseed	2		0	5	8
Cow peas, dry			1		
Cucumbers and gherkins	551	66	12	244	
Eggplants (aubergines)	484		206	34	
Fibre crops not elsewhere specified			2	1	81
Fruit, citrus not elsewhere specified		21	188	10	

Crop (Thousand Metric Tonnes)	Indonesia	Malaysia	Philippines	Thailand	Viet Nam
Fruit, fresh not elsewhere specified	1 014	103	244	312	2 903
Fruit, tropical fresh not elsewhere specified	2 919	98	3 314	2 071	
Garlic	14		10	72	
Ginger	108	9	27	165	
Grapefruit (including pomelos)		9	33	326	25
Grapes			0	77	18
Groundnuts, with shell	749	1	30	46	489
Jute				2	9
Kapok fibre	54			45	
Kapok fruit	170			118	
Kapokseed in shell	138			98	
Leeks, other alliaceous vegetables	539		11		
Lemons and limes		5	1	148	
Lettuce and chicory			4	31	
Maize	17 862	45	6 794	4 765	4 605
Maize, green	447			261	
Mangoes, mangosteens, guavas	1 887	72	810	2 540	607
Manila fibre (abaca)	1		67		
Melons, other (Including Cantaloupes)	92		10		
Millet					2
Mushrooms and truffles	49		1	7	21
Nutmeg, mace and cardamoms	16	1			
Nuts not elsewhere specified	112		7	19	5
Oil, palm	20 178	17 823	90	1 402	
Oil, palm fruit	96 500	87 825	541	9 054	
Oilseeds not elsewhere specified		162	11		
Okra		32	28		
Onions, dry	969		130	46	324
Onions, shallots, green			-	193	
Oranges	1 993	52	4	398	651
Palm kernels	5 450	4 501	25	321	
Papayas	802	45	167	210	
Peas, dry			0		
Peas, green			7	6	
Pepper (piper spp.)	82	20	3	6	141
Pigeon peas			1		
Pineapples	1 502	340	2 205	2 138	518
Potatoes	1 078		121	135	403

Crop (Thousand Metric Tonnes)	Indonesia	Malaysia	Philippines	Thailand	Viet Nam
Pulses not elsewhere specified	1		32	113	121
Pumpkins, squash and gourds	373	18	337	202	
Ramie			2		
Rice, paddy	65 536	2 547	16 241	34 096	40 451
Roots and tubers, not elsewhere specified	372	4	16	225	
Rubber, natural	2 755	918	133	3 164	751
Seed cotton	4		0	8	12
Sesame seed				47	20
Sisal	0			0	
Sorghum			0	54	
Soybeans	908		1	176	260
Spices not elsewhere specified	7	1		3	
Spinach	162		1		
Strawberries			1		
String beans			118		
Sugar cane	25 667	817	30 167	77 192	16 437
Sugar crops not elsewhere specified	190				
Sunflower seed				22	
Sweet potatoes	2 100	20	539		1 297
Tangerines, mandarins, clementines, satsumas			19	385	
Taro (cocoyam)			112	95	
Tea	150	16		68	197
Tobacco, unmanufactured	148	6	41	63	49
Tomatoes	900	99	202	143	
Vanilla	3				
Vegetables, fresh not elsewhere specified	609	498	4 675	1 084	7 871
Vegetables, leguminous not elsewhere specified				2	
Watermelons	440	237	103	542	432
Wheat				1	
Yams			21		

Source: FAO (2015)

Table R-3 Harvest and process residues by country in 2010

Harvest and process residue factors, in tonnes of residue per tonne of crop (columns 3 and 5), can be multiplied by the amounts of each crop produced (from Table R-2) and the share of residues collected (assumed here to be 25% for harvest residues and 90% for process residues) to calculate amounts of harvest and process residues collected (shown in columns 4 and 6). A separate table is generated for each country, and specific factors are applied for each crop. Crops not produced are not shown.

Table R-3a Harvest and process residues in Indonesia

(Indonesia) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Cassava	Cassava	1.0	5 831	0.2	3 778
Cotton	Cotton lint	3.5	1	0.0	-
Cottonseed	Cottonseed	13.3	8	0.1	0
Cottonseed	Seed cotton	13.3	12	0.1	0
Fruit	Avocados	2.0	128	0.2	45
Fruit	Bananas	2.0	3 090	0.2	1 096
Fruit	Fruit, fresh not elsewhere specified	2.0	515	0.2	182
Fruit	Fruit, tropical fresh not elsewhere specified	2.0	1 482	0.2	525
Fruit	Mangoes, mangosteens, guavas	2.0	958	0.2	340
Fruit	Melons, other (including cantaloupes)	2.0	-	0.2	-
Fruit	Oranges	2.0	1 012	0.2	359
Fruit	Papayas	2.0	407	0.2	144
Fruit	Pineapples	2.0	762	0.2	270
Fruit	Watermelons	2.0	223	0.2	79
Groundnut	Groundnuts, with shell	2.3	437	0.3	202
Jute	Bast fibres, other	2.0	2	0.0	-
Jute	Manila fibre (abaca)	2.0	0	0.0	-
Jute	Sisal	2.0	0	0.0	-
Maize	Maize	1.5	6 698	0.2	2 894
Maize	Maize, green	1.5	167	0.2	72
Palm kernels	Coconuts	3.0	13 625	0.5	7 358
Palm kernels	Oil, palm fruit	3.0	72 375	0.5	39 083
Palm kernels	Palm kernels	3.0	4 088	0.5	2 207
Potatoes	Potatoes	0.7	180	0.3	320
Pulses	Beans, dry	2.3	184	0.0	-
Pulses	Beans, green	2.3	527	0.0	-
Pulses	Pulses not elsewhere specified	2.3	1	0.0	-
Rice	Rice, paddy	1.3	21 718	0.2	13 566

(Indonesia) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Soybeans	Soybeans	2.3	530	0.2	172
Spices	Chillies and peppers, green	3.0	1 049	0.0	-
Spices	Cinnamon (canella)	3.0	72	0.0	-
Spices	Cloves	3.0	64	0.0	-
Spices	Pepper (piper spp.)	3.0	61	0.0	-
Spices	Spices not elsewhere specified	3.0	5	0.0	-
Spices	Vanilla	3.0	2	0.0	-
Stimulants	Cocoa, beans	2.3	460	0.0	-
Stimulants	Coffee, green	2.3	389	0.0	-
Stimulants	Tea	2.3	87	0.0	-
Sugar cane	Sugar cane	0.3	1 810	0.2	4 620
Sugar cane	Sugar crops not elsewhere specified	0.3	13	0.2	34
Sweet potatoes	Sweet potatoes	0.8	430	0.3	529
Treenuts	Areca nuts	2.3	106	0.7	119
Treenuts	Cashew nuts, with shell	2.3	81	0.7	91
Treenuts	Castor oil seed	2.3	1	0.7	1
Treenuts	Kapok fruit	2.3	99	0.7	112
Treenuts	Nuts not elsewhere specified	2.3	65	0.7	74
Vegetables	Cabbages and other brassicas	0.4	140	0.2	246
Vegetables	Carrots and turnips	0.4	44	0.2	77
Vegetables	Cauliflowers and broccoli	0.4	11	0.2	19
Vegetables	Cucumbers and gherkins	0.4	56	0.2	99
Vegetables	Eggplants (aubergines)	0.4	49	0.2	87
Vegetables	Garlic	0.4	1	0.2	3
Vegetables	Ginger	0.4	11	0.2	19
Vegetables	Leeks, other alliaceous vegetables	0.4	55	0.2	97
Vegetables	Mushrooms and truffles	0.4	5	0.2	9
Vegetables	Onions, dry	0.4	99	0.2	174
Vegetables	Pumpkins, squash and gourds	0.4	38	0.2	67
Vegetables	Spinach	0.4	17	0.2	29
Vegetables	Tomatoes	0.4	92	0.2	162

(Indonesia) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Vegetables	Vegetables, fresh not elsewhere specified	0.4	62	0.2	110
Yams & other roots	Roots and tubers not elsewhere specified	0.7	62	0.2	60

Source: Smeets, Faaij and Lewandowki (2004) and IRENA analysis

Table R-3b Harvest and process residues in Malaysia

(Malaysia) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Cassava	Cassava	1.0	12	0.2	8
Fruit	Bananas	2.0	160	0.2	57
Fruit	Fruit, citrus not elsewhere specified	2.0	11	0.2	4
Fruit	Fruit, fresh not elsewhere specified	2.0	52	0.2	18
Fruit	Fruit, tropical fresh not elsewhere specified	2.0	50	0.2	18
Fruit	Grapefruit (including pomelos)	2.0	5	0.2	2
Fruit	Lemons and limes	2.0	2	0.2	1
Fruit	Mangoes, mangosteens, guavas	2.0	37	0.2	13
Fruit	Oranges	2.0	26	0.2	9
Fruit	Papayas	2.0	23	0.2	8
Fruit	Pineapples	2.0	173	0.2	61
Fruit	Watermelons	2.0	120	0.2	43
Groundnut	Groundnuts, with shell	2.3	0	0.3	0
Maize	Maize	1.5	17	0.2	7
Palm kernels	Coconuts	3.0	397	0.5	214
Palm kernels	Oil, palm fruit	3.0	65 869	0.5	35 569
Palm kernels	Palm kernels	3.0	3 376	0.5	1 823
Rapeseed	Oilseeds not elsewhere specified	3.0	122	0.3	44
Rice	Rice, paddy	1.3	844	0.2	527
Spices	Spices not elsewhere specified	3.0	1	0.0	-
Stimulants	Cocoa, beans	2.3	10	0.0	-
Stimulants	Coffee, green	2.3	9	0.0	-
Stimulants	Tea	2.3	9	0.0	-

(Malaysia) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Sugar cane	Sugar cane	0.3	58	0.2	147
Sweet potatoes	Sweet potatoes	0.8	4	0.3	5
Treenuts	Areca nuts	2.3	0	0.7	0
Treenuts	Cashew nuts, with shell	2.3	8	0.7	9
Vegetables	Cabbages and other brassicas	0.4	12	0.2	21
Vegetables	Cucumbers and gherkins	0.4	7	0.2	12
Vegetables	Ginger	0.4	1	0.2	2
Vegetables	Okra	0.4	3	0.2	6
Vegetables	Pumpkins, squash and gourds	0.4	2	0.2	3
Vegetables	Tomatoes	0.4	10	0.2	18
Vegetables	Vegetables, fresh not elsewhere specified	0.4	51	0.2	90
Yams & other roots	Roots and tubers, not elsewhere specified	0.7	1	0.2	1

Source: Smeets, Faaij and Lewandowki (2004) and IRENA analysis

Table R-3c Harvest and process residues in the Philippines

(Philippines) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Cassava	Cassava	1.0	530	0.2	343
Fruit	Avocados	2.0	11	0.2	4
Fruit	Bananas	2.0	4 615	0.2	1 637
Fruit	Fruit, citrus not elsewhere specified	2.0	95	0.2	34
Fruit	Fruit, fresh not elsewhere specified	2.0	124	0.2	44
Fruit	Fruit, tropical fresh not elsewhere specified	2.0	1 682	0.2	596
Fruit	Grapefruit (including pomelos)	2.0	17	0.2	6
Fruit	Lemons and limes	2.0	1	0.2	0
Fruit	Mangoes, mangosteens, guavas	2.0	411	0.2	146
Fruit	Oranges	2.0	2	0.2	1
Fruit	Papayas	2.0	85	0.2	30

(Philippines) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Fruit	Pineapples	2.0	1 119	0.2	397
Fruit	Strawberries	2.0	0	0.2	0
Fruit	Tangerines, mandarins, clementines, satsumas	2.0	10	0.2	3
Fruit	Watermelons	2.0	52	0.2	19
Groundnut	Groundnuts, with shell	2.3	18	0.3	8
Jute	Agave fibres not elsewhere specified	2.0	2	0.0	-
Jute	Fibre crops not elsewhere specified	2.0	1	0.0	-
Jute	Manila fibre (abaca)	2.0	33	0.0	-
Jute	Ramie	2.0	1	0.0	-
Maize	Maize	1.5	2 548	0.2	1 101
Palm kernels	Coconuts	3.0	11 606	0.5	6 267
Palm kernels	Oil, palm fruit	3.0	406	0.5	219
Palm kernels	Palm kernels	3.0	19	0.5	10
Potatoes	Potatoes	0.7	20	0.3	36
Pulses	Beans, dry	2.3	17	0.0	-
Pulses	Beans, green	2.3	11	0.0	-
Pulses	Cow peas, dry	2.3	1	0.0	-
Pulses	Pigeon peas	2.3	1	0.0	-
Pulses	Pulses not elsewhere specified	2.3	18	0.0	-
Rapeseed	Oilseeds not elsewhere specified	3.0	9	0.3	3
Rice	Rice, paddy	1.3	5 382	0.2	3 362
Spices	Chillies and peppers, green	3.0	16	0.0	-
Spices	Pepper (piper spp.)	3.0	3	0.0	-
Stimulants	Cocoa, beans	2.3	3	0.0	-
Stimulants	Coffee, green	2.3	54	0.0	-
Sugar cane	Sugar cane	0.3	2 127	0.2	5 430
Sweet potatoes	Sweet potatoes	0.8	110	0.3	136
Treenuts	Cashew nuts, with shell	2.3	74	0.7	83
Treenuts	Nuts not elsewhere specified	2.3	4	0.7	4
Vegetables	Asparagus	0.4	1	0.2	1
Vegetables	Cabbages and other brassicas	0.4	13	0.2	23
Vegetables	Carrots and turnips	0.4	7	0.2	12

(Philippines) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Vegetables	Cauliflowers and broccoli	0.4	1	0.2	2
Vegetables	Chicory roots	0.4	0	0.2	1
Vegetables	Cucumbers and gherkins	0.4	1	0.2	2
Vegetables	Eggplants (aubergines)	0.4	21	0.2	37
Vegetables	Garlic	0.4	1	0.2	2
Vegetables	Ginger	0.4	3	0.2	5
Vegetables	Leeks, other alliaceous vegetables	0.4	1	0.2	2
Vegetables	Lettuce and chicory	0.4	0	0.2	1
Vegetables	Okra	0.4	3	0.2	5
Vegetables	Onions, dry	0.4	13	0.2	23
Vegetables	Peas, green	0.4	1	0.2	1
Vegetables	Pumpkins, squash and gourds	0.4	34	0.2	61
Vegetables	Tomatoes	0.4	21	0.2	36
Vegetables	Vegetables, fresh not elsewhere specified	0.4	477	0.2	842
Yams & other roots	Roots and tubers not elsewhere specified	0.7	3	0.2	3
Yams & other roots	Taro (cocoyam)	0.7	19	0.2	18
Yams & other roots	Yams	0.7	3	0.2	3

Source: Smeets, Faaij and Lewandowki (2004) and IRENA analysis

Table R-3d Harvest and process residues in Thailand

(Thailand) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Barley	Barley	1.5	7	0.3	5
Cassava	Cassava	1.0	6 167	0.2	3 996
Cereals, other	Canary seed	1.5	13	0.3	8
Cereals, other	Cereals not elsewhere specified	1.5	77	0.3	46
Cotton	Cotton lint	3.5	2	0.0	-
Cottonseed	Cottonseed	13.3	17	0.1	0
Cottonseed	Seed cotton	13.3	27	0.1	1

(Thailand) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Fruit	Bananas	2.0	797	0.2	283
Fruit	Fruit, citrus not elsewhere specified	2.0	5	0.2	2
Fruit	Fruit, fresh not elsewhere specified	2.0	159	0.2	56
Fruit	Fruit, tropical fresh not elsewhere specified	2.0	1 051	0.2	373
Fruit	Grapefruit (including pomelos)	2.0	166	0.2	59
Fruit	Grapes	2.0	39	0.2	14
Fruit	Lemons and limes	2.0	75	0.2	27
Fruit	Mangoes, mangosteens, guavas	2.0	1 289	0.2	457
Fruit	Oranges	2.0	202	0.2	72
Fruit	Papayas	2.0	107	0.2	38
Fruit	Pineapples	2.0	1 085	0.2	385
Fruit	Tangerines, mandarins, clementines, satsumas	2.0	195	0.2	69
Fruit	Watermelons	2.0	275	0.2	98
Groundnut	Groundnuts, with shell	2.3	27	0.3	13
Jute	Bast fibres, other	2.0	1	0.0	-
Jute	Jute	2.0	1	0.0	-
Maize	Maize	1.5	1 787	0.2	772
Maize	Maize, green	1.5	98	0.2	42
Palm kernels	Coconuts	3.0	934	0.5	504
Palm kernels	Oil, palm fruit	3.0	6 791	0.5	3 667
Palm kernels	Palm kernels	3.0	241	0.5	130
Potatoes	Potatoes	0.7	23	0.3	40
Pulses	Beans, dry	2.3	59	0.0	-
Pulses	Beans, green	2.3	177	0.0	-
Pulses	Pulses not elsewhere specified	2.3	66	0.0	-
Rapeseed	Sesame seed	3.0	36	0.3	13
Rice	Rice, paddy	1.3	11 299	0.2	7 058
Sorghum	Sorghum	2.3	31	0.1	5
Soybeans	Soybeans	2.3	103	0.2	33
Spices	Chillies and peppers, dry	3.0	116	0.0	-
Spices	Chillies and peppers, green	3.0	13	0.0	-

(Thailand) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Spices	Pepper (piper spp.)	3.0	4	0.0	-
Spices	Spices not elsewhere specified	3.0	2	0.0	-
Stimulants	Coffee, green	2.3	29	0.0	-
Stimulants	Tea	2.3	40	0.0	-
Sugar cane	Sugar cane	0.3	5 443	0.2	13 894
Sunflowers	Sunflower seed	0.0	-	0.3	6
Treenuts	Areca nuts	2.3	22	0.7	25
Treenuts	Cashew nuts, with shell	2.3	20	0.7	23
Treenuts	Castor oil seed	2.3	7	0.7	8
Treenuts	Kapok fruit	2.3	69	0.7	78
Treenuts	Nuts not elsewhere specified	2.3	11	0.7	13
Vegetables	Asparagus	0.4	6	0.2	11
Vegetables	Cabbages and other brassicas	0.4	52	0.2	92
Vegetables	Cauliflowers and broccoli	0.4	4	0.2	7
Vegetables	Cucumbers and gherkins	0.4	25	0.2	44
Vegetables	Eggplants (aubergines)	0.4	4	0.2	6
Vegetables	Garlic	0.4	7	0.2	13
Vegetables	Ginger	0.4	17	0.2	30
Vegetables	Lettuce and chicory	0.4	3	0.2	6
Vegetables	Mushrooms and truffles	0.4	1	0.2	1
Vegetables	Onions, dry	0.4	5	0.2	8
Vegetables	Onions, shallots, green	0.4	20	0.2	35
Vegetables	Peas, green	0.4	1	0.2	1
Vegetables	Pumpkins, squash and gourds	0.4	21	0.2	36
Vegetables	Tomatoes	0.4	15	0.2	26
Vegetables	Vegetables, fresh not elsewhere specified	0.4	111	0.2	195
Yams & other roots	Roots and tubers not elsewhere specified	0.7	37	0.2	36
Yams & other roots	Taro (cocoyam)	0.7	16	0.2	15

Source: Smeets, Faaij and Lewandowki (2004) and IRENA analysis

Table R-3e Harvest and process residues in Viet Nam

(Viet Nam) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Cassava	Cassava	1.0	2 252	0.2	1 459
Cotton	Cotton lint	3.5	4	0.0	-
Cottonseed	Cottonseed	13.3	28	0.1	1
Cottonseed	Seed cotton	13.3	41	0.1	1
Fruit	Bananas	2.0	751	0.2	266
Fruit	Berries not elsewhere specified	2.0	73	0.2	26
Fruit	Fruit, fresh not elsewhere specified	2.0	1 473	0.2	522
Fruit	Grapefruit (including pomelos)	2.0	13	0.2	5
Fruit	Grapes	2.0	9	0.2	3
Fruit	Mangoes, mangosteens, guavas	2.0	308	0.2	109
Fruit	Oranges	2.0	331	0.2	117
Fruit	Pineapples	2.0	263	0.2	93
Fruit	Watermelons	2.0	219	0.2	78
Groundnut	Groundnuts, with shell	2.3	285	0.3	132
Jute	Fibre crops not elsewhere specified	2.0	41	0.0	-
Jute	Jute	2.0	4	0.0	-
Maize	Maize	1.5	1 727	0.2	746
Millet	Millet	2.3	1	0.1	0
Palm kernels	Coconuts	3.0	873	0.5	471
Potatoes	Potatoes	0.7	67	0.3	120
Pulses	Beans, dry	2.3	112	0.0	-
Pulses	Pulses not elsewhere specified	2.3	70	0.0	-
Rapeseed	Sesame seed	3.0	15	0.3	5
Rice	Rice, paddy	1.3	13 405	0.2	8 373
Soybeans	Soybeans	2.3	152	0.2	49
Spices	Chillies and peppers, dry	3.0	66	0.0	-
Spices	Cinnamon (canella)	3.0	15	0.0	-
Spices	Pepper (piper spp.)	3.0	106	0.0	-

(Viet Nam) Commodity Group	Commodity	Harvest Residue Factor	Harvest Residue (000 tonnes)	Process Residue Factor	Process Residue (000 tonnes)
Stimulants	Coffee, green	2.3	669	0.0	-
Stimulants	Tea	2.3	115	0.0	-
Sugar cane	Sugar cane	0.3	1 159	0.2	2 959
Sweet potatoes	Sweet potatoes	0.8	265	0.3	327
Treenuts	Cashew nuts, with shell	2.3	709	0.7	798
Treenuts	Castor oil seed	2.3	4	0.7	4
Treenuts	Nuts not elsewhere specified	2.3	3	0.7	3
Vegetables	Cabbages and other brassicas	0.4	79	0.2	139
Vegetables	Cauliflowers and broccoli	0.4	3	0.2	5
Vegetables	Mushrooms, truffles	0.4	2	0.2	4
Vegetables	Onions, dry	0.4	33	0.2	58
Vegetables	Vegetables, fresh not elsewhere specified	0.4	804	0.2	1 417

Source: Smeets, Faaij and Lewandowki (2004) and IRENA analysis

Table R-4 Growth rates for crop output

Separate rates of growth in crop output are assumed for each country, according to projections by FAO. Output is assumed to grow more slowly from 2030 to 2050 than from 2010 through 2030, as populations and food requirements stabilise. The rates of growth are applied to estimates of collectable residue in 2010 (calculated by crop in Table R-3, summed in columns 2-4 of Table R-1a) to project collectable residue in 2030 and 2050 (columns 2-4 of Tables R-1b, R-1c).

Country	Annual Growth in Crop Output 2010-2030	Annual Growth in Crop Output 2030-2050	Information: Calories per Capita in 2010
Indonesia	1.1%	0.3%	2 510
Malaysia	1.1%	0.4%	2 857
Philippines	1.1%	0.3%	2 474
Thailand	1.1%	0.4%	2 887
Viet Nam	1.1%	0.3%	2 566

Source: Alexandratos *et al.* (2012)

Table R-5 Livestock production by type and country in 2010 (tons)

Livestock production in 2010 is shown as the basis for projecting livestock production in 2030 and 2050, which is multiplied by residue consumed per tonne of livestock to find total residue eaten by livestock.

Crop (Item)	Indonesia	Malaysia	Philippines	Thailand	Viet Nam
Beef	418 949	28 614	286 725	199 679	339 150
Dairy	1 075 060	64 262	13 827	785 325	290 933
Mutton	120 514	1 969	0	1 698	0
Pork	627 513	200 403	1 617 566	917 728	2 827 100
Poultry	1 383 528	1 065 533	825 528	1 225 085	530 247

Source: FAO (2015)

Table R-6 Growth rates for livestock output

FAO projected growth rates for livestock output are applied to livestock production in 2010 (Table R-5) to calculate livestock production in 2030 and 2050, from which residue eaten by livestock can be found.

Country	Annual Growth in Livestock 2010-2030	Annual Growth in Livestock 2030-2050
Indonesia	1.8%	0.8%
Malaysia	1.1%	1.1%
Philippines	1.8%	0.8%
Thailand	1.1%	1.1%
Viet Nam	1.8%	0.8%

Source: Alexandratos *et al.* (2012)

Table R-7 Livestock feed demand coefficients

For each livestock type and production system (mixed or pastoral), livestock residue demand intensity (in tonnes of residue per tonne of livestock) is calculated as the product of feed conversion efficiency (tonnes of feed per tonne of livestock) and residue feed share (tonnes of residue per tonne of feed). Insofar as livestock feeds from pasture, there is no consumption of residues from agricultural crops. Multiplying the amounts of livestock (from Tables R-5 and R-6) by the fraction of livestock raised in a mixed system and the residue intensity, it is possible to calculate the amounts of residue consumed by livestock (Table R-8). Residue intensity is assumed to be the same in 2050 as in 2030, the latest year of relevant FAO projections.

Table R-7a Livestock feed demand coefficients for Indonesia

Livestock Type	System	System Share		Feed Conversion Efficiency (Tonnes Feed per Tonne Livestock)		Residue Feed Share (Tonnes Residue per Tonne Feed)		Residue Intensity (Tonnes Residue per Tonne Livestock)	
		2010	2030	2010	2030	2010	2030	2010	2030
Beef	Mixed	0.88	0.90	63	54	0.27	0.27	15.3	13.4
Beef	Pastoral	0.12	0.10	133	92	0.00	0.00	0.0	0.0
Dairy	Mixed	0.99	1.00	3	2	0.35	0.35	1.1	0.8
Dairy	Pastoral	0.01	0.00	3	3	0.00	0.00	0.0	0.0
Mutton_ or goat	Mixed	0.83	0.89	14	12	0.04	0.04	0.5	0.4
Mutton_ or goat	Pastoral	0.17	0.11	25	21	0.00	0.00	0.0	0.0
Pork	Mixed	1.00	1.00	7	6	0.60	0.60	3.9	3.9
Poultry	Mixed	1.00	1.00	4	4	0.65	0.65	2.6	2.4

Source: Bouwman *et al.* (2005) and IRENA analysis

Table R-7b Livestock feed demand coefficients for Malaysia

Livestock Type	System	System Share		Feed Conversion Efficiency (Tonnes Feed per Tonne Livestock)		Residue Feed Share (Tonnes Residue per Tonne Feed)		Residue Intensity (Tonnes Residue per Tonne Livestock)	
		2010	2030	2010	2030	2010	2030	2010	2030
Beef	Mixed	0.88	0.90	63	54	0.27	0.27	15.3	13.4
Beef	Pastoral	0.12	0.10	133	92	0.00	0.00	0.0	0.0
Dairy	Mixed	0.99	1.00	3	2	0.35	0.35	1.1	0.8
Dairy	Pastoral	0.01	0.00	3	3	0.00	0.00	0.0	0.0
Mutton_ or goat	Mixed	0.83	0.89	14	12	0.04	0.04	0.5	0.4
Mutton_ or goat	Pastoral	0.17	0.11	25	21	0.00	0.00	0.0	0.0
Pork	Mixed	1.00	1.00	7	6	0.60	0.60	3.9	3.9
Poultry	Mixed	1.00	1.00	4	4	0.65	0.65	2.6	2.4

Source: Bouwman *et al.* (2005) and IRENA analysis

Table R-7c Livestock feed demand coefficients for the Philippines

Livestock Type	System	System Share		Feed Conversion Efficiency (Tonnes Feed per Tonne Livestock)		Residue Feed Share (Tonnes Residue per Tonne Feed)		Residue Intensity (Tonnes Residue per Tonne Livestock)	
		2010	2030	2010	2030	2010	2030	2010	2030
Beef	Mixed	0.88	0.90	63	54	0.27	0.27	15.3	13.4
Beef	Pastoral	0.12	0.10	133	92	0.00	0.00	0.0	0.0
Dairy	Mixed	0.99	1.00	3	2	0.35	0.35	1.1	0.8
Dairy	Pastoral	0.01	0.00	3	3	0.00	0.00	0.0	0.0
Mutton or goat	Mixed	0.83	0.89	14	12	0.04	0.04	0.5	0.4
Mutton or goat	Pastoral	0.17	0.11	25	21	0.00	0.00	0.0	0.0
Pork	Mixed	1.00	1.00	7	6	0.60	0.60	3.9	3.9
Poultry	Mixed	1.00	1.00	4	4	0.65	0.65	2.6	2.4

Source: Bouwman *et al.* (2005) and IRENA analysis

Table R-7d Livestock feed demand coefficients for Thailand

Livestock Type	System	System Share		Feed Conversion Efficiency (Tonnes Feed per Tonne Livestock)		Residue Feed Share (Tonnes Residue per Tonne Feed)		Residue Intensity (Tonnes Residue per Tonne Livestock)	
		2010	2030	2010	2030	2010	2030	2010	2030
Beef	Mixed	0.88	0.90	63	54	0.27	0.27	15.3	13.4
Beef	Pastoral	0.12	0.10	133	92	0.00	0.00	0.0	0.0
Dairy	Mixed	0.99	1.00	3	2	0.35	0.35	1.1	0.8
Dairy	Pastoral	0.01	0.00	3	3	0.00	0.00	0.0	0.0
Mutton_ or goat	Mixed	0.83	0.89	14	12	0.04	0.04	0.5	0.4
Mutton_ or goat	Pastoral	0.17	0.11	25	21	0.00	0.00	0.0	0.0
Pork	Mixed	1.00	1.00	7	6	0.60	0.60	3.9	3.9
Poultry	Mixed	1.00	1.00	4	4	0.65	0.65	2.6	2.4

Source: Bouwman *et al.* (2005) and IRENA analysis

Table R-7e Livestock feed demand coefficients for Viet Nam

Livestock Type	System	System Share		Feed Conversion Efficiency (Tonnes Feed per Tonne Livestock)		Residue Feed Share (Tonnes Residue per Tonne Feed)		Residue Intensity (Tonnes Residue per Tonne Livestock)	
		2010	2030	2010	2030	2010	2030	2010	2030
Beef	Mixed	0.88	0.90	63	54	0.27	0.27	15.3	13.4
Beef	Pastoral	0.12	0.10	133	92	0.00	0.00	0.0	0.0
Dairy	Mixed	0.99	1.00	3	2	0.35	0.35	1.1	0.8
Dairy	Pastoral	0.01	0.00	3	3	0.00	0.00	0.0	0.0
Mutton_ or goat	Mixed	0.83	0.89	14	12	0.04	0.04	0.5	0.4
Mutton_ or goat	Pastoral	0.17	0.11	25	21	0.00	0.00	0.0	0.0
Pork	Mixed	1.00	1.00	7	6	0.60	0.60	3.9	3.9
Poultry	Mixed	1.00	1.00	4	4	0.65	0.65	2.6	2.4

Source: Bouwman *et al.* (2005) and IRENA analysis

Table R-8 Residue demand for animal feed

Residue demand for feed is calculated as the product of tonnes of livestock of each type (from Tables R-5 and R-6), the share of each type raised in mixed systems (from Table R-7), and residue intensity (tonnes of residue per tonne of livestock, also from Table R-7). The total residue used for feed in each country, in tonnes, is then converted to PJ of energy equivalent, assuming 15 GJ per ton, in column 5 of Tables R-1a, R-1b and R-1c.

Country	Livestock Type	System	Residue Demand for Feed (Tonnes)		
			2010	2030	2050
Indonesia	Beef	Mixed	6 426 210	8 004 695	9 387 619
	Dairy	Mixed	1 185 517	1 162 511	1 363 351
	Mutton or goat	Mixed	55 758	73 541	86 246
Malaysia	Beef	Mixed	438 907	476 245	592 725
	Dairy	Mixed	70 864	60 532	75 337
	Mutton or goat	Mixed	911	1 046	1 302
Philippines	Beef	Mixed	4 398 045	5 478 347	6 424 809
	Dairy	Mixed	15 247	14 951	17 534
Thailand	Beef	Mixed	3 062 850	3 323 405	4 136 246
	Dairy	Mixed	866 014	739 744	920 671
	Mutton or goat	Mixed	785	902	1 123
Viet Nam	Beef	Mixed	5 202 192	6 480 018	7 599 533
	Dairy	Mixed	320 825	314 599	368 950

Appendix II: Bioenergy potential from higher agricultural yields in Southeast Asia

Table Y-1 Biomass potential from land freed by higher crop yields – summary

The amount of land freed up for bioenergy production in each country is calculated as the difference between land required in the FAO base case scenario, which fully provides for anticipated food needs, and reduced amounts of land required in the more ambitious yield growth scenarios. In the "trend" scenario, crop yields continue to improve at the same absolute pace as they have improved historically. In the "GAP" scenario, the yield gap between current and potential lands, as calculated by FAO, is completely closed through yield improvements. Land freed, shown in the second column from the right, is multiplied by a notional yield of 150 GJ/ha to arrive at primary biomass potential from using this land.

Subsequent tables show the data used to calculate the figures in these summary tables. Land needed for food in each case (in hectares) equals food required (in tons) divided by yield (in tons per hectare). Table Y-2 shows the calculation of food required. Tables Y-3 and Y-4 show the calculation of yields.

Table Y-1a Biomass potential from land freed by higher crop yields in Indonesia

Indonesia	Land Needed for Food Production (Thousand Hectares)						Land Freed	Biomass Potential
Scenario	Cereal	Roots	Sugar	Pulses	Oilcrops	Total	(k ha)	(PJ)
2010	12 563	797	485	407	941	15 194		
2030_FAO	12 917	766	608	390	1 326	16 007		
2030_Trend	12 573	815	582	409	1 432	15 812	195	29
2030_GAP	9 092	531	456	213	901	11 193	4 814	722
2050_FAO	12 498	685	662	354	1 414	15 613		
2050_Trend	10 493	704	564	355	1 493	14 058	1 555	233
2050_GAP	9 146	494	516	202	999	11 357	4 256	638

Source: FAO (2015) and IRENA analysis

Table Y-1b Biomass potential from land freed by higher crop yields in Malaysia

Malaysia	Land Needed for Food Production (Thousand Hectares)						Land Freed	Biomass Potential
Scenario	Cereal	Roots	Sugar	Pulses	Oilcrops	Total	(k ha)	(PJ)
2010	1 916	124	56	40	60	2 196		
2030_FAO	2 217	134	80	43	95	2 569		
2030_Trend	2 065	139	76	46	105	2 433	136	20
2030_GAP	952	74	62	22	68	1 178	1 391	209
2050_FAO	2 118	118	85	38	100	2 460		
2050_Trend	1 743	118	74	40	113	2 088	372	56
2050_GAP	958	68	70	21	76	1 193	1 267	190

Source: FAO (2015) and IRENA analysis

Table Y-1c Biomass potential from land freed by higher crop yields in the Philippines

Philippines	Land Needed for Food Production (Thousand Hectares)						Land Freed	Biomass
Scenario	Cereal	Roots	Sugar	Pulses	Oilcrops	Total		Potential
2010	7 264	696	147	229	1 565	9 901	(k ha)	(PJ)
2030_FAO	8 677	776	213	255	2 563	12 485		
2030_Trend	7 850	754	212	258	2 291	11 365	1 120	168
2030_GAP	3 445	276	191	96	1 252	5 260	7 225	1 084
2050_FAO	8 395	694	232	232	2 733	12 287		
2050_Trend	6 497	606	216	216	2 074	9 609	2 678	402
2050_GAP	9 146	257	216	90	1 388	5 417	6 870	1 031

Source: FAO (2015) and IRENA analysis

Table Y-1d Biomass potential from land freed by higher crop yields in Thailand

Thailand	Land Needed for Food Production (Thousand Hectares)						Land Freed	Biomass
Scenario	Cereal	Roots	Sugar	Pulses	Oilcrops	Total		Potential
2010	5 823	205	112	141	401	6 682	(k ha)	(PJ)
2030_FAO	5 447	179	128	123	514	6 391		
2030_Trend	4 843	192	127	127	538	5 827	564	85
2030_GAP	1 915	159	102	46	417	2 640	3 751	563
2050_FAO	5 202	158	138	111	541	6 149		
2050_Trend	3 964	167	126	108	547	4 913	1 236	185
2050_GAP	1 927	148	116	44	462	2 696	3 453	518

Source: FAO (2015) and IRENA analysis

Table Y-1e Biomass potential from land freed by higher crop yields in Viet Nam

Viet Nam	Land Needed for Food Production (Thousand Hectares)						Land Freed	Biomass
Scenario	Cereal	Roots	Sugar	Pulses	Oilcrops	Total		Potential
2010	4 288	348	173	204	1 465	6 477	(k ha)	(PJ)
2030_FAO	4 368	331	214	194	2 046	7 153		
2030_Trend	4 297	347	206	197	1 831	6 879	274	41
2030_GAP	2 542	110	154	73	1 175	4 053	3 100	465
2050_FAO	4 226	296	233	176	2 182	7 113		
2050_Trend	3 770	296	200	166	1 659	6 092	1 021	153
2050_GAP	2 557	102	175	68	1 302	4 205	2 908	436

Source: FAO (2015) and IRENA analysis

Table Y-2 Calculation of food crop requirements

Crop needs by food type in each country (in Tables Y2c-g) are calculated by multiplying projected population (Table Y-2a) by projected food crop demand per capita for each type of crop (Table Y-2b).

In Table Y-2b, adjustment factors account for cereal allocation to processing and tonnes of sugar cane required for each tonne of sugar; no adjustment is made for other crops, for which factors are set to 1.0.

Table Y-2a Population projections (thousand people)

Country	Element	Unit	2010	2030	2050
Indonesia	Population	1000	239 871	279 659	321 377
Malaysia	Population	1000	28 401	37 266	42 113
Philippines	Population	1000	93 261	126 321	157 118
Thailand	Population	1000	69 122	73 321	61 740
Viet Nam	Population	1000	87 848	101 483	103 697

Source: FAO (2015)

Table Y-2b Annual food and crop demand per capita (kilograms)

Commodity	Food Demand (Kg/capita)			Adjustment factor (Food demand → Crop demand)			Crop Demand (Kg/capita)		
	2006	2030	2050	2010	2030	2050	2006	2030	2050
Cereals	163	162	157	1.6	1.6	1.7	254	259	260
Roots	60	57	53	1.0	1.0	1.0	60	57	53
Sugar	13.4	16.6	18.8	8.9	8.9	8.9	119	147	166
Pulses	1.9	1.8	1.7	1.0	1.0	1.0	2	2	2
Oil crop	9.9	13.8	15.3	1.0	1.0	1.0	10	14	15
Meat	44.3	61.2	71.1	1.0	1.0	1.0	44	61	71
Milk and dairy	23.3	34.6	39.2	1.0	1.0	1.0	23	35	39
Other	367	422	455	1.0	1.0	1.0	367	422	455
Total	2 850	3 130	3 220	1.0	1.0	1.0	2 850	3 130	3 220

Source: Alexandratos *et al.* (2012) and IRENA analysis

Table Y-2c Projected food demand in Indonesia (thousand tonnes per year)

Year	Cereals	Roots	Sugar	Pulses	Oil Crop	Meat	Dairy	Other	Total
2006	61 045	14 392	28 464	456	2 375	10 626	5 589	88 033	683 632
2030	72 374	15 941	41 110	503	3 859	17 115	9 676	118 016	875 333
2050	72 807	14 822	46 559	475	4 279	19 884	10 963	127 245	900 502

Source: Alexandratos *et al.* (2012) and IRENA analysis

Table Y-2d Projected food demand in Malaysia (thousand tonnes per year)

Year	Cereals	Roots	Sugar	Pulses	Oil Crop	Meat	Dairy	Other	Total
2006	7 228	1 704	3 370	54	281	1 258	662	10 423	80 943
2030	9 644	2 124	5 478	67	514	2 281	1 289	15 726	116 643
2050	9 702	1 975	6 204	63	570	2 650	1 461	16 956	119 997

Source: Alexandratos *et al.* (2012) and IRENA analysis

Table Y-2e Projected food demand in the Philippines (thousand tonnes per year)

Year	Cereals	Roots	Sugar	Pulses	Oil Crop	Meat	Dairy	Other	Total
2006	23 734	5 596	11 067	177	923	4 131	2 173	34 227	265 794
2030	32 691	7 200	18 569	227	1 743	7 731	4 371	53 307	395 385
2050	32 887	6 695	21 030	215	1 933	8 981	4 952	57 476	406 754

Source: Alexandratos *et al.* (2012) and IRENA analysis

Table Y-2f Projected food demand in Thailand (thousand tonnes per year)

Year	Cereals	Roots	Sugar	Pulses	Oilcrops	Meat	Dairy	Other	Total
2006	22 622	2 947	11 525	111	727	3 062	7 732	17 531	128 611
2030	25 803	2 762	11 057	114	757	3 292	8 135	18 463	129 774
2050	26 295	2 724	11 057	117	795	3 443	8 399	19 258	132 044

Source: Alexandratos *et al.* (2012) and IRENA analysis

Table Y-2g Projected food demand in Viet Nam (thousand tonnes per year)

Year	Cereals	Roots	Sugar	Pulses	Oilcrops	Meat	Dairy	Other	Total
2006	6 310	822	3 214	31	203	854	2 157	4 890	35 871
2030	7 031	753	3 013	31	206	897	2 216	5 031	35 360
2050	7 165	742	3 013	32	216	938	2 289	5 247	35 978

Source: Alexandratos *et al.* (2012) and IRENA analysis

Table Y-3 Definition of yield growth scenarios

Three scenarios of yield growth are defined. Table Y-3a shows a scenario based on FAO yield growth projections. Table Y-3b shows a scenario based on the historical trend of yield growth, based on regression analysis of global yields by crop from 1961 through 2013 (the regression curve slope shows the average annual increase in yield in tonnes per hectare). Table Y-3c shows a scenario based on the FAO's assessment of the "yield gap" between actual and potential yields on rain-fed and irrigated land. For each crop, the ratio of actual to potential yield is calculated by taking a weighted average yield of hectares in different yield categories (assuming that hectares yielding <10%, 10-25%, 25-40%, 40-55%, 55-70%, 70-85% and >85% of potential respectively yield 5%, 17.5%, 32.5%, 47.5%, 62.5%, 77.5% and 92.5% of potential respectively) and dividing by total hectares.

Table Y-3a Yield growth scenario from FAO projections

Country	Region	Yield Growth Per Annum		Yield Growth index		
		2010-2030	2030-2050	2010	2030	2050
Indonesia	East Asia	0.7%	0.2%	1.00	1.15	1.20
Malaysia	East Asia	0.7%	0.3%	1.00	1.15	1.21
Philippines	East Asia	0.7%	0.2%	1.00	1.15	1.20
Thailand	East Asia	0.7%	0.3%	1.00	1.15	1.21
Viet Nam	East Asia	0.7%	0.2%	1.00	1.15	1.20
World average	All regions	1.0%	0.5%	1.00	1.21	1.33

Source: Alexandratos *et al.* (2012) and IRENA analysis

Table Y-3b Historical trend of yield growth by crop (global, 1961-2013)

Item	Correlation	Slope (t/ha)	Intercept	Annual%
Cereals	1.00	0.045	-87	1.16%
Roots	0.94	0.075	-137	0.50%
Pulses	0.95	0.006	-10	0.61%
Oil Crops	0.98	0.009	-17	1.26%
Vegetables primary	1.00	0.189	-362	0.97%
Fibre crops primary	0.97	0.009	-16	1.03%
Fruit except melons	0.90	0.060	-110	0.53%
Sugar	0.98	0.599	-1138	0.87%
Total	1.00	0.064	-122	1.07%

[Yield] = [Year] * [slope] + [intercept]

Table Y-3c Yield gap (difference between actual and potential yield, as share of potential)

Country	Cereals	Roots	Oil Crops	Pulses	Sugar Cane	Sugar Beet	Sugars
Indonesia	0.39	0.40	0.41	0.53	0.35	0.53	0.35
Malaysia	0.63	0.52	0.37	0.55	0.33	0.53	0.33
Philippines	0.66	0.69	0.58	0.68	0.23	0.53	0.23
Thailand	0.70	0.23	0.30	0.68	0.31	0.53	0.31
Viet Nam	0.50	0.71	0.50	0.68	0.38	0.53	0.38

[Yield GAP] = ([potential yield] – [actual yield]) / [potential yield]

Table Y-4 Projected crop yields by country for different yield growth scenarios

Projected crop yields are shown for each country, as follows, for three distinct scenarios:

Yield gap closure case: Future crop yields reaching the full productive potential of rain-fed and irrigated lands are calculated by dividing 2010 crop yields by the ratio of current to potential yield, which is [1 - yield gap] from Y-3c. Values are the same for 2030 and 2050, since the gap is independent of time.

Historical trend case: Future crop yields with continuation of the historical trend of yield growth are calculated by adding to 2010 crop yields the historical annual increment in yield from Table Y-3b for 20 or 40 years. Yield values are not allowed to exceed those in the yield gap closure case.

FAO projection case: Future crop yields according to FAO projections are calculated by multiplying 2010 crop yields by yield increase indices from Table Y-3a. Again, yield values are not allowed to exceed those in the yield gap closure case.

Table Y-4a Projected crop yields for Indonesia (tonnes per hectare)

	Cereals	Roots	Sugars	Pulses	Oil Crops
2010	4.9	18.1	58.6	1.1	2.5
2030_FAO	5.6	20.8	67.6	1.3	2.9
2030_Trend	5.8	19.6	70.6	1.2	2.7
2030_GAP	8.0	30.0	90.2	2.4	4.3
2050_FAO	5.8	21.6	70.3	1.3	3.0
2050_Trend	6.7	21.1	82.6	1.3	2.9
2050_GAP	8.0	30.0	90.2	2.4	4.3

Source: FAO (2015) and IRENA analysis

Table Y-4b Projected crop yields for Malaysia (tonnes per hectare)

	Cereals	Roots	Sugars	Pulses	Oil Crops
2010	3.8	13.7	59.8	1.4	4.7
2030_FAO	4.3	15.8	68.9	1.6	5.4
2030_Trend	4.7	15.2	71.7	1.5	4.9
2030_GAP	10.1	28.9	89.0	3.0	7.5
2050_FAO	4.6	16.7	72.6	1.6	5.7
2050_Trend	5.6	16.7	83.7	1.6	5.0
2050_GAP	10.1	28.9	89.0	3.0	7.5

Source: FAO (2015) and IRENA analysis

Table Y-4c Projected crop yields for the Philippines (tonnes per hectare)

	Cereals	Roots	Sugars	Pulses	Oil Crops
2010	3.3	8.0	75.5	0.8	0.6
2030_FAO	3.8	9.3	87.1	0.9	0.7
2030_Trend	4.2	9.5	87.5	0.9	0.8
2030_GAP	9.5	26.1	97.4	2.4	1.4
2050_FAO	3.9	9.6	90.5	0.9	0.7
2050_Trend	5.1	11.0	97.4	1.0	0.9
2050_GAP	9.5	26.1	97.4	2.4	1.4

Source: FAO (2015) and IRENA analysis

Table Y-4d Projected crop yields for Thailand (tonnes per hectare)

	Cereals	Roots	Sugars	Pulses	Oil Crops
2010	3.0	20.2	73.1	0.9	1.7
2030_FAO	3.5	23.3	84.2	1.1	2.0
2030_Trend	3.9	21.7	85.0	1.0	1.9
2030_GAP	9.9	26.2	105.5	2.9	2.4
2050_FAO	3.7	24.6	88.7	1.1	2.1
2050_Trend	4.8	23.2	97.0	1.1	2.1
2050_GAP	9.9	26.2	105.5	2.9	2.4

Source: FAO (2015) and IRENA analysis

Table Y-4e Projected crop yields for Viet Nam (tonnes per hectare)

	Cereals	Roots	Sugars	Pulses	Oil Crops
2010	5.2	15.1	60.4	0.8	0.6
2030_FAO	6.0	17.5	69.6	0.9	0.7
2030_Trend	6.1	16.6	72.3	0.9	0.8
2030_GAP	10.3	52.8	96.8	2.5	1.2
2050_FAO	6.3	18.2	72.4	1.0	0.7
2050_Trend	7.0	18.1	84.3	1.0	0.9
2050_GAP	10.3	52.8	96.8	2.5	1.2

Source: FAO (2015) and IRENA analysis

Appendix III: Bioenergy potential from reduced food waste in Southeast Asia

Table W-1 Biomass potential from land freed by reduced food waste – summary

For crops consumed directly, land potentially freed (thousand ha or kha) equals food waste (tonnes, Table W-7) divided by crop yield (t/ha, Table W-10b). For milk and meat, land freed is food waste multiplied by unit land demand (hectares per tonne, Table W-9b). Land freed is converted to potential biomass at a notional 150 GJ/ha (assuming typical crop yield of 15 t/ha and energy content of 10 GJ/t).

Tables W-1a-d assume **FAO projections of crop yields**. Tables W-1a-b show land freed and biomass potential by food type with projected FAO yields. Tables W-1c-d show these by stage of the food chain.

Table W-1a Potential land freed by reduced food waste, by food type – FAO case (kha)

Country	Year	Total	Cereals	Roots	Oil Crops	Pulse	Fruits	Vegetables	Meat	Milk
Indonesia	2010	11 147	3 617	647	3 550	82	448	607	2 478	80
Indonesia	2030	12 584	3 903	698	3 832	89	484	655	2 851	73
Indonesia	2050	13 792	3 986	713	3 913	90	494	1 221	3 291	84
Malaysia	2010	3 128	145	2	1 577	-	71	47	1 259	27
Malaysia	2030	3 252	156	2	1 702	-	76	29	1 263	22
Malaysia	2050	3 608	161	3	1 751	-	78	45	1 544	27
Philippines	2010	7 800	1 486	158	1 052	24	749	277	4 003	53
Philippines	2030	8 519	1 603	171	1 135	25	808	450	4 282	45
Philippines	2050	9 944	1 637	174	1 159	26	825	1 242	4 830	51
Thailand	2010	6 905	2 732	540	357	67	728	221	2 204	55
Thailand	2030	7 121	2 949	583	385	72	786	283	2 022	41
Thailand	2050	8 306	3 032	599	396	74	808	958	2 389	48
Viet Nam	2010	7 027	1 821	307	175	111	335	446	3 804	29
Viet Nam	2030	7 778	1 965	332	189	119	362	411	4 374	27
Viet Nam	2050	8 420	2 007	339	193	122	369	315	5 045	31

Table W-1b Potential biomass on land freed by reduced food waste, by food type – FAO case (PJ)

Country	Year	Total	Cereals	Roots	Oil Crops	Pulses	Fruits	Vegetables	Meat	Milk
Indonesia	2010	1 672	543	97	533	12	67	37	372	12
Indonesia	2030	1 888	585	105	575	13	73	98	428	11
Indonesia	2050	2 069	598	107	587	14	74	183	494	13
Malaysia	2010	469	22	0	237	0	11	7	189	4
Malaysia	2030	488	23	0	255	0	11	4	189	3
Malaysia	2050	541	24	0	263	0	12	7	232	4
Philippines	2010	1 170	223	24	158	4	112	42	600	8
Philippines	2030	1 278	240	26	170	4	121	67	642	7
Philippines	2050	1 492	246	26	174	4	124	186	725	8
Thailand	2010	1 036	410	81	54	10	109	33	331	8
Thailand	2030	1 068	442	87	58	11	118	42	303	6
Thailand	2050	1 246	455	90	59	11	121	144	358	7
Viet Nam	2010	1 054	273	46	26	17	50	67	571	4
Viet Nam	2030	1 167	295	50	28	18	54	62	656	4
Viet Nam	2050	1 263	301	51	29	18	55	47	757	5

Table W-1c **Potential land freed by reduced food waste, by food chain stage – FAO case (kha)**

Country	Year	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Indonesia	2010	11 147	2 990	3 149	2 423	1 532	1 053
Indonesia	2030	12 584	3 384	3 456	2 803	1 748	1 194
Indonesia	2050	13 792	3 716	3 619	3 162	1 973	1 323
Malaysia	2010	3 128	818	745	754	527	284
Malaysia	2030	3 252	850	798	782	533	288
Malaysia	2050	3 608	943	827	869	629	339
Philippines	2010	7 800	2 094	1 233	1 869	1 629	975
Philippines	2030	8 519	2 292	1 349	2 064	1 758	1 056
Philippines	2050	9 944	2 688	1 502	2 511	2 031	1 212
Thailand	2010	6 905	1 872	1 508	1 515	1 189	821
Thailand	2030	7 121	1 938	1 623	1 565	1 166	828
Thailand	2050	8 306	2 269	1 775	1 935	1 376	951
Viet Nam	2010	7 027	1 886	1 036	1 615	1 540	950
Viet Nam	2030	7 778	2 083	1 111	1 781	1 738	1 066
Viet Nam	2050	8 420	2 247	1 128	1 918	1 949	1 179

Table W-1d **Potential biomass on land freed by reduced food waste, by food chain stage – FAO (PJ)**

Country	Year	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Indonesia	2010	1 672	448	472	363	230	158
Indonesia	2030	1 888	508	518	420	262	179
Indonesia	2050	2 069	557	543	474	296	198
Malaysia	2010	469	123	112	113	79	43
Malaysia	2030	488	128	120	117	80	43
Malaysia	2050	541	141	124	130	94	51
Philippines	2010	1 170	314	185	280	244	146
Philippines	2030	1 278	344	202	310	264	158
Philippines	2050	1 492	403	225	377	305	182
Thailand	2010	1 036	281	226	227	178	123
Thailand	2030	1 068	291	243	235	175	124
Thailand	2050	1 246	340	266	290	206	143
Viet Nam	2010	1 054	283	155	242	231	143
Viet Nam	2030	1 167	312	167	267	261	160
Viet Nam	2050	1 263	337	169	288	292	177

Tables W-1e-h assume enhanced crop yields to **close the "yield gap"** between actual and potential yields that the FAO has identified. Tables W-1e-f show land freed and biomass potential by food type with the yield gap closed. Tables W-1g-h show these by stage of the food chain. Land freed is less in the yield cap closure case than in the FAO base case since yields are higher; reducing waste saves less land. Fruits and vegetables are unaffected since the FAO yield gap closure case does not consider them.

Table W-1e Potential land freed by reduced food waste, by food type – yield gap closure case (kha)

Country	Year	Total	Cereals	Roots	Oil Crops	Pulse	Fruits	Vegetables	Meat	Milk
Indonesia	2030	9 793	2 748	485	2 602	48	484	655	2 703	69
Indonesia	2050	10 970	2 917	514	2 763	51	494	1 221	2 934	74
Malaysia	2030	2 515	67	1	1 227	-	76	29	1 095	19
Malaysia	2050	2 801	73	1	1 329	-	78	45	1 253	21
Philippines	2030	5 929	637	61	555	10	808	450	3 376	35
Philippines	2050	6 804	676	64	589	10	825	1 242	3 364	34
Thailand	2030	4 568	1 037	518	312	27	786	283	1 661	33
Thailand	2050	5 661	1 123	561	338	29	808	958	1 808	35
Viet Nam	2030	6 152	1 144	110	108	45	362	411	3 949	24
Viet Nam	2050	6 412	1 214	116	115	47	369	315	4 209	25

Table W-1f Potential biomass on land freed by reduced food waste, by food type – yield gap closure case (PJ)

Country	Year	Total	Cereals	Roots	Oil Crops	Pulses	Fruits	Vegetables	Meat	Milk
Indonesia	2030	1 469	412	73	390	7	73	98	405	10
Indonesia	2050	1 645	438	77	414	14	74	183	440	11
Malaysia	2030	377	10	0	184	0	11	4	164	3
Malaysia	2050	420	11	0	199	0	12	7	188	3
Philippines	2030	889	95	9	83	1	121	67	506	5
Philippines	2050	1 021	101	10	88	2	124	186	505	5
Thailand	2030	699	156	78	47	4	118	42	249	5
Thailand	2050	849	168	84	51	4	121	144	271	5
Viet Nam	2030	923	172	16	16	7	54	62	592	4
Viet Nam	2050	962	182	17	17	7	55	47	631	4

Table W-1g **Potential land freed by reduced food waste, by food chain stage – yield gap closure case (kha)**

Country	Year	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Indonesia	2030	9 793	2 633	2 450	2 240	1 490	979
Indonesia	2050	10.970	2 961	2 678	2 584	1 660	1 087
Malaysia	2030	2 515	656	568	612	443	236
Malaysia	2050	2 801	731	618	683	503	267
Philippines	2030	5 929	1 592	717	1 531	1 329	760
Philippines	2050	6 804	1 847	866	1 848	1 422	822
Thailand	2030	4 658	1 225	904	1 142	867	921
Thailand	2050	5 661	1 506	1 069	1 467	1 010	609
Viet Nam	2030	6 152	1 651	670	1 473	1 481	877
Viet Nam	2050	6 412	1 718	691	1 516	1 563	924

Table W-1h **Potential biomass on land freed by reduced food waste, by food chain stage – yield gap closure case (PJ)**

Country	Year	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Indonesia	2030	1 469	395	367	336	224	147
Indonesia	2050	1 645	444	402	388	249	163
Malaysia	2030	377	98	85	92	66	35
Malaysia	2050	420	110	93	102	75	40
Philippines	2030	889	239	108	230	199	114
Philippines	2050	1 021	277	130	277	213	123
Thailand	2030	699	184	136	171	130	78
Thailand	2050	849	226	160	220	151	91
Viet Nam	2030	923	248	100	221	222	131
Viet Nam	2050	962	258	104	227	234	139

Table W-2 Biomass potential from land freed by food waste best practice – summary

Land freed by applying global best practice for waste and loss reduction equals total land encumbered by waste and losses (thousand ha or kha, Table W-1) less land still encumbered with best practice applied. For crops consumed directly, land still encumbered equals food waste (kt, Table W-7a-e(ii)) divided by crop yield (t/ha, Table W-10b). For milk and meat, land still encumbered is food waste multiplied by unit land demand (hectares per tonne, Table W-8b). Land freed is converted to potential biomass at a notional 150 GJ/ha (assuming typical crop yield of 15 t/ha and energy content of 10 GJ/t).

Tables W-2a-d assume **FAO projections of crop yields**. Tables W-2a-b show land freed and biomass potential by food type with projected FAO yields. Tables W-2c-d show these by stage of the food chain.

Table W-2a Potential land freed by food waste best practice, by food type – FAO case (kha)

Country	Year	Total	Cereals	Roots	Oil Crops	Pulse	Fruits	Vegetables	Meat	Milk
Indonesia	2010	5 328	1 851	247	1 924	44	234	128	836	62
Indonesia	2030	6 003	1 997	267	2 077	48	253	342	962	57
Indonesia	2050	6 555	2 040	273	2 121	49	258	638	1 110	69
Malaysia	2010	1 437	74	1	855	-	37	24	425	21
Malaysia	2030	1 502	80	1	923	-	40	15	426	17
Malaysia	2050	1 638	82	1	949	-	41	24	521	21
Philippines	2010	3 331	760	61	570	13	391	145	1 351	41
Philippines	2030	3 652	820	65	615	14	422	235	1 445	35
Philippines	2050	4 296	838	67	628	14	431	649	1 630	39
Thailand	2010	3 118	1 398	207	193	36	381	116	744	43
Thailand	2030	3 253	1 509	223	209	39	411	148	682	32
Thailand	2050	3 803	1 552	229	215	40	422	501	806	38
Viet Nam	2010	2 918	932	118	95	60	175	233	1 283	23
Viet Nam	2030	3 200	1 006	327	102	65	189	215	1 476	21
Viet Nam	2050	3 411	1 027	130	104	66	193	165	1 703	24

Table W-2b Potential biomass on land freed by food waste best practice, by food type – FAO (PJ)

Country	Year	Total	Cereals	Roots	Oil Crops	Pulses	Fruits	Vegetables	Meat	Milk
Indonesia	2010	799	278	37	289	7	35	19	125	9
Indonesia	2030	900	300	40	312	7	38	51	144	5
Indonesia	2050	983	306	41	318	7	39	96	167	10
Malaysia	2010	216	11	0	128	0	6	4	64	3
Malaysia	2030	225	12	0	138	0	6	2	64	3
Malaysia	2050	246	12	0	142	0	6	4	78	3
Philippines	2010	500	114	9	85	2	59	22	203	6
Philippines	2030	548	123	10	92	2	63	35	217	5
Philippines	2050	644	126	10	94	2	65	97	244	6
Thailand	2010	468	210	31	29	5	57	17	112	6
Thailand	2030	488	226	33	31	6	62	22	102	5
Thailand	2050	570	233	34	32	6	63	75	121	6
Viet Nam	2010	438	140	18	14	9	26	35	193	3
Viet Nam	2030	480	151	19	15	10	28	32	221	3
Viet Nam	2050	512	154	19	16	10	29	25	255	4

Table W-2c Potential land freed by food waste best practice, by food chain stage – FAO case (kha)

Country	Year	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Indonesia	2010	5 328	1 248	2 630	453	511	495
Indonesia	2030	6 003	1 409	2 869	621	566	538
Indonesia	2050	6 555	1 542	2 979	826	627	580
Malaysia	2010	1 437	249	711	152	217	108
Malaysia	2030	1 502	256	763	156	219	108
Malaysia	2050	1 638	293	788	166	260	131
Philippines	2010	3 331	919	959	415	593	445
Philippines	2030	3 652	1 003	1 044	499	628	477
Philippines	2050	4 296	1 161	1 134	779	697	524
Thailand	2010	3 118	935	1 076	323	1378	406
Thailand	2030	3 253	973	1 159	363	351	408
Thailand	2050	3 803	1 108	1 250	603	398	445
Viet Nam	2010	2 918	907	725	267	559	461
Viet Nam	2030	3 200	1 002	777	263	638	519
Viet Nam	2050	3 411	1 079	789	233	733	578

Table W-2d Potential biomass on land freed by food waste best practice, by food chain stage – FAO case (PJ)

Country	Year	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Indonesia	2010	799	187	395	68	77	73
Indonesia	2030	900	211	430	93	85	81
Indonesia	2050	983	231	447	124	94	87
Malaysia	2010	216	37	107	23	33	16
Malaysia	2030	225	38	114	23	33	16
Malaysia	2050	246	44	118	25	39	20
Philippines	2010	500	138	144	62	89	67
Philippines	2030	548	150	157	75	94	72
Philippines	2050	644	174	170	117	105	79
Thailand	2010	468	140	161	48	57	61
Thailand	2030	488	146	174	54	53	61
Thailand	2050	570	166	187	90	60	67
Viet Nam	2010	438	136	109	40	84	89
Viet Nam	2030	480	150	117	39	96	78
Viet Nam	2050	512	162	118	35	110	87

Tables W-2e-h assume enhanced crop yields to ***close the "yield gap"*** between actual and potential yields that FAO has identified. Tables W-2e-f show land freed and biomass potential by food type, with the yield gap closed. Tables W-2g-h show these by stage of the food chain. Land freed is less in the yield cap closure case than in FAO base case since yields are higher; reducing waste saves less land. Fruits and vegetables are unaffected, since the FAO yield gap closure case does not consider them.

Table W-2e Potential land freed by food waste best practice, by food type – yield gap closure case (kha)

Country	Year	Total	Cereals	Roots	Oil Crops	Pulse	Fruits	Vegetables	Meat	Milk
Indonesia	2030	4 589	1 406	185	1 410	26	253	342	912	53
Indonesia	2050	5 159	1 493	197	1 487	28	258	638	990	97
Malaysia	2030	1 139	34	1	1665	-	40	15	370	15
Malaysia	2050	1 262	37	1	720	-	41	24	423	16
Philippines	2030	2 478	326	23	301	5	422	235	1 139	27
Philippines	2050	2 937	346	25	319	5	431	649	1 135	26
Thailand	2030	2 058	531	198	169	15	411	148	561	25
Thailand	2050	2 549	575	215	183	16	422	501	610	27
Viet Nam	2030	2 465	585	42	59	24	189	215	1 333	18
Viet Nam	2050	2 552	621	45	62	26	193	165	1 420	19

Table W-2f Potential biomass on land freed by food waste best practice, by food type – yield gap closure case (PJ)

Country	Year	Total	Cereals	Roots	Oil Crops	Pulses	Fruits	Vegetables	Meat	Milk
Indonesia	2030	688	211	28	212	4	38	51	137	8
Indonesia	2050	774	224	30	225	4	39	96	149	9
Malaysia	2030	171	5	0	100	0	6	2	55	2
Malaysia	2050	189	6	0	108	0	6	4	63	2
Philippines	2030	372	49	3	45	1	63	35	171	4
Philippines	2050	441	52	4	48	1	65	97	170	4
Thailand	2030	309	80	30	25	2	62	22	84	4
Thailand	2050	382	86	32	28	2	63	75	91	4
Viet Nam	2030	370	88	6	9	4	28	32	200	3
Viet Nam	2050	383	93	7	9	4	29	25	213	3

Table W-2g **Potential land freed by food waste best practice, by food chain stage – yield gap closure case (kha)**

Country	Year	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Indonesia	2030	4 589	1 104	2 008	547	493	436
Indonesia	2050	5 159	1 234	2 174	756	527	468
Malaysia	2030	1 139	199	543	123	184	89
Malaysia	2050	1 262	225	590	137	209	102
Philippines	2030	2 478	677	530	468	477	326
Philippines	2050	2 937	772	622	748	467	328
Thailand	2030	2 058	533	634	371	296	223
Thailand	2050	2 549	644	737	612	315	242
Viet Nam	2030	2 465	778	454	265	551	417
Viet Nam	2050	2 552	813	471	235	589	444

Table W-2h **Potential biomass on land freed by food waste best practice, by food chain stage yield gap closure case (PJ)**

Country	Year	Total	Production	Post-Harvest	Processing	Distribution	Consumption
Indonesia	2030	688	166	301	82	74	65
Indonesia	2050	774	185	326	113	79	70
Malaysia	2030	171	30	81	19	28	13
Malaysia	2050	189	34	88	21	31	15
Philippines	2030	372	101	80	70	72	49
Philippines	2050	441	116	93	112	70	49
Thailand	2030	309	80	95	56	44	33
Thailand	2050	382	97	111	92	47	36
Viet Nam	2030	370	117	68	40	83	62
Viet Nam	2050	383	122	71	35	88	67

Table W-3 Food production by item and country in 2010

Data on the amounts of each food item produced in 2010 are used to project food requirements by food type in 2030 and 2050 (in Table W-5), using projected growth rates in food needs (from Table W-4).

Table W-3a Crop production by crop and country in 2010 (thousand tonnes)

Crop (Item)	Indonesia	Malaysia	Philippines	Thailand	Viet Nam
Agave fibres not elsewhere specified			4		
Anise, badian, fennel, coriander					4
Areca nuts	181	1		38	
Asparagus			5	63	
Avocados	253		22		
Bananas	6 087	316	9 093	1 571	1 480
Barley				20	
Bast fibres, other	4			3	
Beans, dry	316		29	101	192
Beans, green	904		19	303	
Berries not elsewhere specified					143
Cabbages and other brassicas	1 369	116	126	512	775
Canary seed				34	
Carrots and turnips	430		69		
Cashew nuts, with shell	138	14	127	35	1 215
Cassava	23 322	48	2 118	24 669	9 008
Castor oil seed	2		0	12	6
Cauliflowers and broccoli	104		11	41	30
Cereals, not elsewhere specified				205	
Chicory roots			4		
Chillies and peppers, dry		2		155	89
Chillies and peppers, green	1 398	31	21	18	
Cinnamon (canella)	96				20
Cloves	85	0			
Cocoa, beans	789	18	5	1	
Coconuts	18 167	529	15 474	1 245	1 164
Coffee, green	667	16	93	49	1 147
Coir		20		60	282
Cotton lint	1		0	3	4
Cottonseed	2		0	5	8
Cow peas, dry			1		
Cucumbers and gherkins	551	66	12	244	
Eggplants (aubergines)	484		206	34	
Fibre crops not elsewhere specified			2	1	81
Fruit, citrus not elsewhere specified		21	188	10	

Crop (Item)	Indonesia	Malaysia	Philippines	Thailand	Viet Nam
Fruit, fresh not elsewhere specified	1 014	103	244	312	2 903
Fruit, tropical fresh not elsewhere specified	2 919	98	3 314	2 071	
Garlic	14		10	72	
Ginger	108	9	27	165	
Grapefruit (including pomelos)		9	33	326	25
Grapes			0	77	18
Groundnuts, with shell	749	1	30	46	489
Jute				2	9
Kapok fibre	54			45	
Kapok fruit	170			118	
Kapokseed in shell	138			98	
Leeks, other alliaceous vegetables	539		11		
Lemons and limes		5	1	148	
Lettuce and chicory			4	31	
Maize	17 862	45	6 794	4 765	4 605
Maize, green	447			261	
Mangoes, mangosteens, guavas	1 887	72	810	2 540	607
Manila fibre (abaca)	1		67		
Melons, other (including Cantaloupe)	92		10		
Millet					2
Mushrooms and truffles	49		1	7	21
Nutmeg, mace and cardamoms	16	1			
Nuts not elsewhere specified	112		7	19	5
Oil, palm	20 178	17 823	90	1 402	
Oil, palm fruit	96 500	87 825	541	9 054	
Oilseeds not elsewhere specified		162	11		
Okra		32	28		
Onions, dry	969		130	46	324
Onions, shallots, green			-	193	
Oranges	1 993	52	4	398	651
Palm kernels	5 450	4 501	25	321	
Papayas	802	45	167	210	
Peas, dry			0		
Peas, green			7	6	
Pepper (piper spp.)	82	20	3	6	141
Pigeon peas			1		
Pineapples	1 502	340	2 205	2 138	518
Potatoes	1 078		121	135	403
Pulses not elsewhere specified	1		32	113	121

Crop (Item)	Indonesia	Malaysia	Philippines	Thailand	Viet Nam
Pumpkins, squash and gourds	373	18	337	202	
Ramie			2		
Rice, paddy	65 536	2 547	16 241	34 096	40 451
Roots and tubers, not elsewhere specified	372	4	16	225	
Rubber, natural	2 755	918	133	3 164	751
Seed cotton	4		0	8	12
Sesame seed				47	20
Sisal	0			0	
Sorghum			0	54	
Soybeans	908		1	176	260
Spices, not elsewhere specified	7	1		3	
Spinach	162		1		
Strawberries			1		
String beans			118		
Sugar cane	25 667	817	30 167	77 192	16 437
Sugar crops, not elsewhere specified	190				
Sunflower seed				22	
Sweet potatoes	2 100	20	539		1 297
Tangerines, mandarins, clementines, satsumas			19	385	
Taro (cocoyam)			112	95	
Tea	150	16		68	197
Tobacco, unmanufactured	148	6	41	63	49
Tomatoes	900	99	202	143	
Vanilla	3				
Vegetables, fresh, not elsewhere specified	609	498	4 675	1 084	7 871
Vegetables, leguminous, not elsewhere specified				2	
Watermelons	440	237	103	542	432
Wheat				1	
Yams			21		

Source: FAO (2015)

Table W-3b Livestock production by type and country in 2010 (tonnes)

Livestock Type	Indonesia	Malaysia	Philippines	Thailand	Viet Nam
Beef	418 949	28 614	286 725	199 679	339 150
Dairy	1 075 060	64 262	13 827	785 325	290 933
Mutton	120 514	1 969	0	1 698	0
Pork	627 513	200 403	1 617 566	917 728	2 827 100
Poultry	1 383 528	1 065 533	825 528	1 225 085	530 247

Source: FAO (2015)

Table W-4 Projected rates of growth in crop and livestock output

Table W-4a Projected growth rates for crop output

Separate rates of growth in crop output are assumed for each country, according to projections by FAO. Output is assumed to grow more slowly from 2030 through 2050 than from 2010 through 2030, as populations and food requirements stabilise. The rates of growth are applied to baseline data for 2010 (from Table W-3a, summed by type in the 2010 row of the W-5 tables) to project crop output by type in 2030 and 2050 (in remaining rows of the W-5 tables).

Country	Annual Growth in Crop Output 2010-2030	Annual Growth in Crop Output 2030-2050	Information: Calories per Capita in 2010
Indonesia	1.1%	0.3%	2 510
Malaysia	1.1%	0.4%	2 857
Philippines	1.1%	0.3%	2 474
Thailand	1.1%	0.4%	2 887
Viet Nam	1.1%	0.3%	2 566

Source: Alexandratos *et al.* (2012)

Table W-4b Projected growth rates for livestock output

FAO projected growth rates for livestock output are applied to livestock production in 2010 (Table W-3b) to calculate livestock production in 2030 and 2050 (in the W-5 tables).

Country	Annual Growth in Livestock 2010-2030	Annual Growth in Livestock 2030-2050
Indonesia	1.8%	0.8%
Malaysia	1.1%	1.1%
Philippines	1.8%	0.8%
Thailand	1.1%	1.1%
Viet Nam	1.8%	0.8%

Source: Alexandratos *et al.* (2012)

Table W-5 Projected food production by food type and country

The baseline data for 2010 (from Table W-3) is grouped here by food type. Projected growth rates (from Table W-4) are then applied to estimate food production by food type in 2030 and 2050.

Table W-5a Projected food production in Indonesia (thousand tonnes per year)

Indonesia	Cereals	Roots	Oil Crops	Pulses	Fruits	Vegetables	Meat	Milk	Total
2010	83 399	26 872	142 268	317	16 989	9 300	2 623	2 649	284 417
2030	103 796	33 444	177 065	395	21 144	11 575	3 748	3 784	354 951
2050	110 205	35 509	187 997	419	22 450	12 290	4 396	4 438	377 702

Table W-5b Projected food production in Malaysia (thousand tonnes per year)

Malaysia	Cereals	Roots	Oil Crops	Pulses	Fruits	Vegetables	Meat	Milk	Total
2010	2 592	73	110 841	0	1 298	861	1 466	1 021	118 151
2030	3 226	90	137 950	0	1 616	1 072	1 825	1 271	147 049
2050	3 494	98	149 416	0	1 750	1 161	2 271	1 582	159 770

Table W-5c Projected food production in the Philippines (thousand tonnes per year)

Philippines	Cereals	Roots	Oil Crops	Pulses	Fruits	Vegetables	Meat	Milk	Total
2010	23 035	2 928	16 172	63	16 213	5 996	2 944	1 193	68 544
2030	28 669	3 644	20 127	78	20 178	7 463	4 206	1 704	86 070
2050	30 439	3 869	21 370	83	21 424	7 924	4 933	1 998	92 041

Table W-5d Projected food production in Thailand (thousand tonnes per year)

Thailand	Cereals	Roots	Oil Crops	Pulses	Fruits	Vegetables	Meat	Milk	Total
2010	39 174	25 123	12 555	214	10 728	3 261	1 914	1 537	94 506
2030	48 755	31 268	15 626	266	13 352	4 059	2 382	1 913	117 620
2050	52 807	33 866	16 924	289	14 462	4 396	2 965	2 381	128 089

Table W-5e Projected food production in Viet Nam (thousand tonnes per year)

Vietnam	Cereals	Roots	Oil Crops	Pulses	Fruits	Vegetables	Meat	Milk	Total
2010	45 058	10 708	1 960	312	6 779	9 022	3 919	939	78 696
2030	56 078	13 327	2 440	389	8 437	11 228	5 599	1 341	98 838
2050	59 541	14 150	2 590	413	8 957	11 921	6 567	1 573	105 711

Table W-6 Waste coefficients by stage of the food chain (waste as share of food)

This table shows the share of food lost or wasted at each stage of the food chain in South and Southeast Asia, as well as the total fraction of food wasted. Table W-6a indicates FAO estimates of actual shares lost or wasted. Table W-6b shows shares that would be lost or wasted if the region attained best practice for each crop and food chain stage among all regions globally. FAO estimates losses and waste at each stage of the food chain (agricultural production, post-harvest handling and storage, processing, packaging, distribution, and consumption) as shares of volumes received from the previous stage. In the table, adjusted values for losses and waste at each stage of the food chain are recalculated as shares of original production volumes and summed to the total share of food lost or wasted. For agricultural production losses, adjusted values are higher than the original ones because they express loss as a share of reported net production rather than as a share of gross production prior to the loss.

The shares of food lost or wasted (from this table) are then multiplied by the amounts of food produced (from Table W-5) to arrive at amounts of food lost or wasted by food type and loss stage (in Table W-7).

The data come from FAO's *Global Food Losses and Food Waste: Extent, Causes and Prevention* (2011). The report was prepared by experts at the Swedish Institute for Food and Biotechnology – SIK (Jenny Gustavsson, Christel Cederberg, Ulf Sonesson) and FAO (Robert van Otterdijk, Alexandre Meybeck). See "Annex 4. Weight percentages of food losses and waste, (in percentage of what enters each step)".

Table W-6a Actual food chain loss and waste coefficients for South and Southeast Asia

Food Type	Total Waste and Losses	Agricultural Production	Postharvest Handling and Storage	Processing and Packaging	Distribution: Supermarket Retail	Consumption Waste
Cereals	0.211	0.064	0.070	0.033	0.018	0.026
Roots	0.434	0.064	0.190	0.081	0.080	0.019
Oil crops, pulses	0.290	0.075	0.120	0.070	0.016	0.008
Fruits, vegetables	0.605	0.176	0.090	0.228	0.068	0.043
Meat	0.208	0.054	0.003	0.050	0.066	0.035
Milk	0.215	0.036	0.060	0.019	0.092	0.008

Source: Gustavsson *et al.* (2011)

Table W-6b Global best practice loss and waste coefficients by food type and food chain stage

Food Type	Total Waste and Losses	Agricultural Production	Postharvest Handling and Storage	Processing and Packaging	Distribution: Supermarket Retail	Consumption Waste
Cereals	0.103	0.020	0.02	0.034	0.019	0.009
Roots	0.268	0.064	0.07	0.093	0.025	0.016
Oil crops, pulses	0.133	0.064	0.00	0.05	0.010	0.009
Fruits, vegetables	0.289	0.111	0.04	0.019	0.075	0.043
Meat	0.138	0.030	0.002	0.05	0.038	0.018
Milk	0.048	0.036	0.005	0.001	0.005	0.001

Source: Gustavsson *et al.* (2011)

Table W-7 Projected food waste by food type and stage of the food chain

Food waste by food type (cereals, roots, oil crops, pulses, fruits, vegetables, meat and dairy) and stage of the food chain (production, post-harvest, processing, distribution, consumption, and total) is found by multiplying food production (from Table W-5) by shares of each food type lost at each stage (Table W-6). In the first table (i) for each country (W-7a-e(i)), total food waste is calculated using Table W-6a. In the second table (ii) for each (W-7a-e(ii)), best practice food waste is shown, using Table W6b.

Table W-7a (i) *Total* food waste by food type and food chain stage in Indonesia (thousand tonnes)

Indonesia	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	17 573	5 323	5 838	2 715	1 497	2 200
Cereal2030	21 871	6 625	7 266	3 379	1 863	2 739
Cereal2050	23 222	7 034	7 714	3 587	1 978	2 908
Root2010	11 675	1 715	5 106	2 177	2 155	523
Root2030	14 531	2 135	6 354	2 709	2 682	651
Root2050	15 428	2 267	6 747	2 876	2 847	691
Oil2010	41 229	10 708	17 072	10 016	2 304	1 129
Oil2030	51 312	13 327	21 248	12 465	2 867	1 405
Oil2050	54 480	14 150	22 560	13 235	3 044	1 492
Pulse2010	92	24	38	22	5	3
Pulse2030	114	30	47	28	6	3
Pulse2050	121	32	50	29	7	3
Fruits2010	10 282	2 998	1 529	3 865	1 160	730
Fruits2030	12 797	3 731	1 903	4 810	1 443	909
Fruits2050	13 587	3 962	2 020	5 107	1 532	965
Vegetable2010	5 629	1 641	837	2 116	635	400
Vegetable2030	7 005	2 043	1 042	2 633	790	498
Vegetable2050	7 438	2 169	1 106	2 796	839	528
Meat2010	546	141	8	131	174	92
Meat2030	781	201	11	187	248	132
Meat2050	915	236	13	219	291	155
Dairy2010	570	96	159	50	244	22
Dairy2030	815	137	227	71	349	31
Dairy2050	956	161	266	83	409	37

Table W-7a (ii) *Best practice* food waste by food type and food chain stage in Indonesia (kt)

Indonesia	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	8 581	1 702	1 668	2 861	1 577	773
Cereal2030	10 670	2 118	7 266	3 560	1 963	962
Cereal2050	11 339	2 249	7 714	3 780	2 084	1 021
Root2010	7 206	1 715	5 106	2 499	675	436
Root2030	8 969	2 135	6 354	3 110	840	543
Root2050	9 523	2 267	6 747	3 302	892	577
Oil2010	18 884	9 080	-	7 113	1 352	1 338
Oil2030	23 503	11 302	-	8 853	1 682	1 665
Oil2050	24 954	12 000	-	9 400	1 786	1 768
Pulse2010	42	20	-	16	3	3
Pulse2030	52	25	-	20	4	4
Pulse2050	56	27	-	21	4	4
Fruits2010	4 907	1 888	680	326	1 279	735
Fruits2030	6 108	2 349	846	406	1 591	915
Fruits2050	6 485	2 494	898	431	1 690	972
Vegetable2010	2 686	1 033	372	179	700	402
Vegetable2030	3 343	1 286	463	222	871	501
Vegetable2050	3 550	1 366	492	236	925	532
Meat2010	362	78	5	131	99	48
Meat2030	516	112	7	187	142	68
Meat2050	606	131	9	219	167	80
Dairy2010	127	96	13	50	13	3
Dairy2030	182	137	19	71	19	4
Dairy2050	214	161	22	83	22	4

Table W-7b (i) *Total* food waste by food type and food chain stage in Malaysia (thousand tonnes)

Malaysia	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	546	165	181	84	47	68
Cereal2030	680	206	226	105	58	85
Cereal2050	736	223	245	114	63	92
Root2010	32	5	14	6	6	1
Root2030	39	6	17	7	7	2
Root2050	42	6	19	8	8	2
Oil2010	32 121	8 343	13 301	7 803	1 795	879
Oil2030	39 977	10 383	16 554	9 712	2 234	1 095
Oil2050	43 300	11 246	17 930	10 519	2 419	1 185
Pulse2010	0	0	0	0	0	0
Pulse2030	0	0	0	0	0	0
Pulse2050	0	0	0	0	0	0
Fruits2010	786	229	117	295	89	56
Fruits2030	978	285	145	368	110	69
Fruits2050	1 059	309	158	398	119	75
Vegetable2010	521	152	77	196	59	37
Vegetable2030	648	189	96	244	73	46
Vegetable2050	702	205	104	264	79	50
Meat2010	305	79	4	73	97	52
Meat2030	380	98	5	91	121	64
Meat2050	473	122	7	113	151	80
Dairy2010	220	37	61	19	94	8
Dairy2030	274	46	76	24	117	10
Dairy2050	341	57	95	30	146	13

Table W-7b (ii) *Best practice* food waste by food type and food chain stage in Malaysia (kt)

Malaysia	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	267	53	52	89	49	624
Cereal2030	332	66	65	111	61	30
Cereal2050	359	71	70	120	66	32
Root2010	19	5	5	7	2	1
Root2030	24	6	6	8	2	1
Root2050	26	6	7	9	2	2
Oil2010	14 712	7 075	0	5 542	1 053	1 042
Oil2030	18 311	8 805	0	6 898	1 311	1 297
Oil2050	19 833	9 537	0	7 471	1 419	1 405
Pulse2010	0	0	0	0	0	0
Pulse2030	0	0	0	0	0	0
Pulse2050	0	0	0	0	0	0
Fruits2010	375	144	52	25	98	56
Fruits2030	467	180	65	31	122	70
Fruits2050	506	194	70	34	132	76
Vegetable2010	249	96	34	17	65	37
Vegetable2030	310	119	43	21	81	46
Vegetable2050	335	129	46	22	87	50
Meat2010	202	44	3	73	56	27
Meat2030	252	54	4	91	69	33
Meat2050	313	68	5	113	86	41
Dairy2010	49	37	5	1	5	1
Dairy2030	61	46	6	1	6	1
Dairy2050	76	57	8	2	8	2

Table W-7c (i) ***Total*** **food waste by food type and food chain stage in Philippines (thousand tonnes)**

Philippines	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	4 854	1 470	1 612	750	413	608
Cereal2030	6 041	1 830	2 007	933	515	756
Cereal2050	6 414	1 943	2 131	991	546	803
Root2010	1 272	187	556	237	235	57
Root2030	1 583	233	692	295	292	71
Root2050	1 681	247	735	313	310	75
Oil2010	4 686	1 217	1 941	1 138	262	128
Oil2030	5 833	1 515	2 415	1 417	326	160
Oil2050	6 193	1 608	2 564	1 504	346	170
Pulse2010	18	5	8	4	1	0
Pulse2030	23	6	9	5	1	1
Pulse2050	24	6	10	6	1	1
Fruits2010	9 812	2 861	1 459	3 688	1 107	697
Fruits2030	12 212	3 561	1 816	4 591	1 377	868
Fruits2050	12 966	3 781	1 928	4 874	1 462	921
Vegetable2010	3 629	1 058	540	1 364	409	258
Vegetable2030	4 517	1 317	672	1 698	509	321
Vegetable2050	4 796	1 398	713	1 803	541	341
Meat2010	613	158	9	147	195	104
Meat2030	875	226	13	210	279	148
Meat2050	1 027	265	15	246	327	174
Dairy2010	257	43	72	22	110	10
Dairy2030	367	62	102	32	157	14
Dairy2050	431	72	120	38	184	17

Table W-7c (ii) ***Best practice*** **food waste by food type and food chain stage in the Philippines (kt)**

Philippines	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	2 370	470	461	790	436	213
Cereal2030	2 950	585	573	983	542	266
Cereal2050	3 132	621	609	1 044	576	282
Root2010	785	187	205	272	74	48
Root2030	977	233	255	339	92	59
Root2050	1 038	247	271	360	97	63
Oil2010	2 147	1 032	0	809	154	152
Oil2030	2 672	1 285	0	1 006	191	189
Oil2050	2 837	1 364	0	1 068	203	201
Pulse2010	8	4	0	3	1	1
Pulse2030	10	5	0	4	1	1
Pulse2050	11	5	0	4	1	1
Fruits2010	4 683	1 801	649	311	1 220	702
Fruits2030	5 829	2 242	807	387	1 519	873
Fruits2050	6 188	2 380	857	411	1 612	927
Vegetable2010	1 732	666	240	115	451	260
Vegetable2030	2 156	829	299	143	562	323
Vegetable2050	2 289	880	317	152	596	343
Meat2010	406	88	6	147	112	54
Meat2030	580	126	8	210	160	77
Meat2050	680	147	10	246	187	90
Dairy2010	58	43	6	1	6	1
Dairy2030	82	62	9	2	8	2
Dairy2050	96	72	10	2	10	2

Table W-7d (i) *Total* food waste by food type and food chain stage in Thailand (thousand tonnes)

Thailand	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	8 254	2 500	2 742	1 275	703	1 034
Cereal2030	10 273	3 112	3 413	1 587	875	1 286
Cereal2050	11 127	3 371	3 696	1 719	948	1 393
Root2010	10 916	1 604	4 773	2 035	2 015	489
Root2030	13 585	1 996	5 941	2 533	2 507	609
Root2050	14 714	2 162	6 435	2 743	2 716	659
Oil2010	3 638	945	1 507	884	203	100
Oil2030	4 528	1 176	1 875	1 100	253	124
Oil2050	4 905	1 274	2 031	1 191	274	134
Pulse2010	62	16	26	15	3	2
Pulse2030	77	20	32	19	4	2
Pulse2050	84	22	35	20	5	2
Fruits2010	6 493	1 893	966	2 441	732	461
Fruits2030	8 081	2 356	1 202	3 038	911	574
Fruits2050	8 753	2 552	1 302	3 290	987	622
Vegetable2010	1 974	575	293	742	223	140
Vegetable2030	2 456	716	365	923	277	175
Vegetable2050	2 661	776	396	1 000	300	189
Meat2010	398	103	6	95	127	67
Meat2030	496	128	7	119	158	84
Meat2050	617	159	9	148	197	104
Dairy2010	331	56	92	29	142	13
Dairy2030	412	69	115	36	176	16
Dairy2050	513	86	143	45	219	20

Table W-7d (ii) ***Best practice*** **food waste by food type and food chain stage in Thailand (kt)**

Thailand	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	4 031	799	783	1 344	741	363
Cereal2030	5 016	995	975	1 672	922	452
Cereal2050	5 433	1 078	1 056	1 811	999	489
Root2010	6 737	1 604	1 759	2 336	631	408
Root2030	8 385	1 996	2 189	2 908	785	508
Root2050	9 082	2 162	2 371	3 150	850	550
Oil2010	1 666	801	0	628	119	118
Oil2030	2 074	997	0	781	148	147
Oil2050	2 246	1 080	0	846	161	159
Pulse2010	28	14	0	11	2	2
Pulse2030	35	17	0	13	3	3
Pulse2050	38	18	0	14	3	3
Fruits2010	3 099	1 192	429	206	807	464
Fruits2030	3 857	1 484	534	256	1 005	578
Fruits2050	4 177	1 607	578	278	1 088	626
Vegetable2010	942	362	130	63	245	141
Vegetable2030	1 172	451	162	78	305	176
Vegetable2050	1 270	488	176	84	331	190
Meat2010	264	57	4	96	73	35
Meat2030	328	71	5	119	90	43
Meat2050	409	89	6	148	112	54
Dairy2010	74	556	8	2	8	2
Dairy2030	92	69	10	2	10	2
Dairy2050	115	86	12	2	12	2

Table W-7e (i) *Total* food waste by food type and food chain stage in Viet Nam (thousand tonnes)

Viet Nam	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	9 494	2 876	3 154	1 467	809	1 189
Cereal2030	11 816	3 579	3 925	1 825	1 007	1 480
Cereal2050	12 546	3 800	4 168	1 938	1 069	1 571
Root2010	4 652	683	2 035	867	859	208
Root2030	5 790	851	2 532	1 079	1 069	259
Root2050	6 148	903	2 688	1 146	1 135	275
Oil2010	568	148	235	138	32	16
Oil2030	707	184	293	172	40	19
Oil2050	751	195	311	182	42	21
Pulse2010	90	24	37	22	5	2
Pulse2030	113	29	47	27	6	3
Pulse2050	120	31	50	29	7	3
Fruits2010	4 103	1 196	610	1 542	463	291
Fruits2030	5 106	1 489	759	1 919	576	363
Fruits2050	5 421	1 581	806	2 038	611	385
Vegetable2010	5 460	1 592	812	2 052	616	388
Vegetable2030	6 795	1 981	1 011	2 554	766	483
Vegetable2050	7 215	2 104	1 073	2 712	814	513
Meat2010	816	211	12	195	260	138
Meat2030	1 165	301	17	279	371	197
Meat2050	1 367	353	20	327	435	231
Dairy2010	202	34	56	18	86	8
Dairy2030	289	49	80	25	124	11
Dairy2050	339	57	94	30	145	13

Table W-7e (ii) ***Best practice*** **food waste by food type and food chain stage in Viet Nam (kt)**

Viet Nam	Total	Production	Postharvest	Processing	Distribution	Consumption
Cereal2010	4 636	920	901	1 545	852	418
Cereal2030	5 770	1 144	1 122	1 973	1 061	520
Cereal2050	6 126	1 215	1 191	2 042	1 126	552
Root2010	2 872	683	750	996	269	174
Root2030	3 574	851	932	1 239	335	216
Root2050	3 795	903	990	1 316	355	230
Oil2010	260	125	0	98	19	18
Oil2030	324	156	0	122	23	23
Oil2050	344	165	0	130	25	24
Pulse2010	41	20	0	16	3	3
Pulse2030	152	25	0	19	4	4
Pulse2050	55	26	0	21	4	4
Fruits2010	1 958	753	271	130	510	293
Fruits2030	2 437	937	337	162	635	365
Fruits2050	2 587	995	358	172	674	387
Vegetable2010	2 606	1 002	361	2 173	679	390
Vegetable2030	2 587	1 248	449	216	845	486
Vegetable2050	3 443	1 325	477	229	897	516
Meat2010	540	117	8	196	149	71
Meat2030	772	167	11	279	212	102
Meat2050	905	196	13	328	249	120
Dairy2010	45	34	5	1	5	1
Dairy2030	65	49	7	1	7	1
Dairy2050	76	57	8	2	8	2

Table W-8 Livestock feed demand coefficients

For each livestock type and production system (mixed or pastoral), livestock feed demand intensity (in tonnes of feed per tonne of livestock) is calculated as the product of system share, feed conversion efficiency (tonnes of feed per tonne of livestock) and grass or crop feed factor (tonnes of grass or crop per tonne of feed). Multiplying feed demand intensity (tonnes of feed per tonne of livestock) by land required per tonne of feed (Table W-9b), the product is land required per tonne of livestock. Multiplying this by tonnes of milk or meat wasted (Table W-7), one may calculate potential land liberated (Tables W-1a, W-1c, W-1e and W-1g). Feed intensities are assumed to be the same in 2050 as in 2030, the latest year of relevant FAO projections. System shares are from Bouwman (2005), Tables 2, 4 and 10.

Table W-8a Grass feed for livestock

Livestock Type	System	System Share		Feed Conversion Efficiency (Tonnes Feed per Tonnes Livestock)		Grass Feed Factor (Tonnes Grass per Tonne Feed)		Grass Intensity (Tonnes Grass per Tonne Livestock)	
		2010	2030	2010	2030	2010	2030	2010	2030
Beef	Mixed	0.88	0.90	63	54	0.55	0.55	30.8	26.9
Beef	Pastoral	0.12	0.10	133	92	0.60	0.60	9.3	5.5
Dairy	Mixed	0.99	1.00	3	2	0.45	0.45	1.4	1.0
Dairy	Pastoral	0.01	0.00	3	3	0.60	0.60	0.0	0.0
Mutton or goat	Mixed	0.83	0.89	14	12	0.85	0.85	10.1	9.3
Mutton or goat	Pastoral	0.17	0.11	25	21	0.70	0.70	3.1	1.6
Pork	Mixed	1.00	1.00	7	6	0.00	0.00	0.0	0.0
Poultry	Mixed	1.00	1.00	4	4	0.00	0.00	0.0	0.0

Source: Bouwman (2005) and IRENA analysis

Table W-8b Crop feed for livestock

Livestock Type	System	System Share		Feed Conversion Efficiency (Tonnes Feed per Tonne Livestock)		Crop Feed Factor (Tonnes Crop per Tonne Feed)		Crop Intensity (Tonnes Crop per Tonne Livestock)	
		2010	2030	2010	2030	2010	2030	2010	2030
Beef	Mixed	0.88	0.90	63	54	0.08	0.08	4.3	3.7
Beef	Pastoral	0.12	0.10	133	92	0.00	0.00	0.0	0.0
Dairy	Mixed	0.99	1.00	3	2	0.10	0.10	0.3	0.2
Dairy	Pastoral	0.01	0.00	3	3	0.00	0.00	0.0	0.0
Mutton or goat	Mixed	0.83	0.89	14	12	0.01	0.01	0.1	0.1
Mutton or goat	Pastoral	0.17	0.11	25	21	0.00	0.00	0.0	0.0
Pork	Mixed	1.00	1.00	7	6	0.40	0.40	2.6	2.6
Poultry	Mixed	1.00	1.00	4	4	0.35	0.35	1.4	1.3

Source: Bouwman (2005) and IRENA analysis

Table W-9 Land intensity of livestock feed

Table W-9a shows FAO projections of how much crop or grass is produced per hectare for animal feed. Animal feed yields for 2030 and 2050 are found by applying indices from Table W-10 to 2010 values. Dividing the amounts of feed required per tonne of livestock from Table W-8 by these feed crop yields, one obtains livestock unit land demands in hectares of land per ton of animal product in table W-9b.

For milk and meat, amounts of land freed by avoiding losses and waste (thousand hectares, Tables W-1 and W-2) can be calculated by multiplying these unit land demands (hectares per tonne, Table W-9b) by amounts lost or wasted (thousand tonnes, Table W-7).

Table W-9a Animal feed yield (tonnes of feed per hectare)

Country	Feed Crop Yield			Feed Grass Yield		
	2010	2030	2050	2010	2030	2050
Indonesia	4.4	5.1	5.3			
Malaysia	5.6	6.5	6.8			
Philippines	2.6	3.0	3.2	15.9	18.3	19.0
Thailand	4.2	4.9	5.1	15.0	17.3	18.2
Viet Nam	4.1	4.8	5.0			

Source: FAO (2015)

Table W-9b Livestock unit land demand (hectares of land per tonne of meat or milk)

Hectares of land required to feed each tonne of livestock (the inverse of livestock yield in tonnes per hectare) is found by dividing livestock feed intensity coefficients (tonnes of grass or crop feed per tonne of livestock, from rightmost columns of Tables W-8a and W-8b) by feed yields (tonnes of feed per hectare, from Table W-9a).

		2010		2030		2050	
		Meat	Milk	Meat	Milk	Meat	Milk
Indonesia	Feed grass	2.6	0.1	2.1	0.0	2.1	0.0
	Feed crop	1.9	0.1	1.5	0.0	1.5	0.0
Malaysia	Feed grass	2.6	0.1	2.1	0.0	2.1	0.0
	Feed crop	1.5	0.1	1.2	0.0	1.1	0.0
Philippines	Feed grass	3.4	0.1	2.4	0.1	2.3	0.1
	Feed crop	3.2	0.1	2.5	0.1	2.4	0.1
Thailand	Feed grass	3.6	0.1	2.5	0.1	2.4	0.1
	Feed crop	2.0	0.1	1.6	0.0	1.5	0.0
Viet Nam	Feed grass	2.6	0.1	2.1	0.0	2.1	0.0
	Feed crop	2.0	0.1	1.6	0.0	1.5	0.0

Table W-10 Current and projected crop yields (FAO projections)

Crop yields (tonnes per hectare) are projected for each type of crop in Table W-10b, based upon growth rates in Table W-10a. Where crops are consumed directly, rather than as animal feed, amounts of land freed by avoiding losses and waste (Tables W-1 and W-2) can be calculated by taking the amount of food lost or wasted (Table W-7) and dividing by these yields (W-10b).

Table W-10a Yield growth scenario from FAO projections

FAO assumptions about the annual increase in yields are shown in this table for 2010-30 and 2030-50. The same increase is assumed for all crops and for all countries in a region – a simplification of reality. Indices of yield (2010 yield = 100) are calculated for 2030 and 2050, based upon these annual increases.

Country	Region	Yield Growth Per Annum		Yield Growth index		
		2010-2030	2030-2050	2010	2030	2050
Indonesia	East Asia	0.7%	0.2%	1.00	1.15	1.20
Malaysia	East Asia	0.7%	0.3%	1.00	1.15	1.21
Philippines	East Asia	0.7%	0.2%	1.00	1.15	1.20
Thailand	East Asia	0.7%	0.3%	1.00	1.15	1.21
Viet Nam	East Asia	0.7%	0.2%	1.00	1.15	1.20
World average	All regions	1.0%	0.5%	1.00	1.21	1.33

Source: Alexandratos *et al.* (2012)

Table W-10b Projected crop yields in FAO yield growth scenario (tonnes per hectare)

FAO data on 2010 crop yields for each country and crop type are projected out to 2030 and 2050 using the general indices of yield improvement developed in Table W-10a.

Country	Year	Cereals	Roots	Sugars	Pulses	Oil Crops	Fruits	Vegetables
Indonesia	2010	4.9	18.1	58.6	1.1	11.6	22.9	9.3
	2030	5.6	20.8	67.6	1.3	13.4	26.5	10.7
	2050	5.8	21.6	70.3	1.3	13.9	27.5	11.1
Malaysia	2010	3.8	13.7	59.8	1.4	20.4	11.1	19.2
	2030	4.3	15.8	68.9	1.6	23.5	12.8	22.2
	2050	4.6	16.7	72.6	1.7	24.7	13.5	23.3
Philippines	2010	3.3	8.0	75.5	0.8	4.5	13.1	8.7
	2030	3.8	9.3	87.1	0.9	5.1	15.1	10.0
	2050	3.9	9.6	90.5	0.9	5.3	15.7	10.4
Thailand	2010	3.0	20.2	73.1	0.9	10.2	8.9	7.5
	2030	3.5	23.3	84.2	1.1	11.8	10.3	8.7
	2050	3.7	24.6	88.7	1.1	12.4	10.8	9.1
Viet Nam	2010	5.2	15.1	60.4	0.8	3.3	12.2	14.3
	2030	6.0	17.5	69.6	0.9	3.7	14.1	16.5
	2050	6.3	18.2	72.4	1.0	3.9	14.7	17.2

Source: Alexandratos *et al.* (2012) and IRENA analysis

**Table W-10c	Projected crop yields in yield gap closure scenario (tonnes per hectare)**

FAO analysis of yields that could be obtained if the yield gap were closed is shown in the table below. Yields for fruits and vegetables are unaffected, since FAO does not consider the yield gap for these crops.

Country	Year	Cereals	Roots	Sugars	Pulses	Oil Crops	Fruits	Vegetables
Indonesia	2010	4.9	18.1	58.6	1.1	11.6	22.9	9.3
	2030	8.0	30.0	90.2	2.4	19.7	26.5	10.7
	2050	8.0	30.0	90.2	2.4	19.7	27.5	11.1
Malaysia	2010	3.8	13.7	59.8	1.4	20.4	11.1	19.2
	2030	10.1	29.9	89.0	3.1	32.6	12.8	22.2
	2050	10.1	29.9	89.0	3.1	32.6	13.5	23.3
Philippines	2010	3.3	8.0	75.5	0.8	4.5	13.1	8.7
	2030	9.5	26.1	97.4	2.4	10.5	15.1	10.0
	2050	9.5	26.1	97.4	2.4	10.5	15.7	10.4
Thailand	2010	3.0	20.2	73.1	0.9	10.2	8.9	7.5
	2030	9.9	26.2	105.5	2.9	14.5	10.3	8.7
	2050	9.9	26.2	105.5	2.9	14.5	10.8	9.1
Viet Nam	2010	5.2	15.1	60.4	0.8	3.3	12.2	14.3
	2030	10.3	52.8	96.8	2.5	6.5	14.1	16.5
	2050	10.3	52.8	96.8	2.5	6.5	14.7	17.2

Source: Alexandratos *et al.* (2012)

Appendix IV: Bioenergy potential from productive forests in Southeast Asia

Table F-1 Wood yields and wood energy shares by species

Annual biomass increment in tons per hectare, below, can be multiplied by plantation areas in thousand hectares from Table F-2 to find the annual, woody biomass increment by crop and country in Table F-3. This increment is generally found by multiplying biomass density from FAO (1997) by increment in cubic meters per hectare per year from FAO (2006) or (for neem trees, *Melia azedarach*) JIFPRO (1996). But for coconut, it is found by multiplying biomass density and increment in cubic meters from FAO (1985).

The energy shares of collected wood by species are classified according to three typical patterns of use:

- P: Pulp (80% of harvested wood assumed used for pulp or paper; 20% available for energy use)
- L + F: Lumber and Furniture/Other (60% used as timber or furniture, 40% energy)
- A + F: Animal fodder and Furniture/Other (85% for non-energy uses, 15% for energy

Species	Biomass Density (tonnes per cubic meter)	Biomass Increment (cubic meters per hectare per year)	Biomass Increment (tonnes per hectare per year)	Wood Type	Energy Wood Share of Total Wood
Acacia mangium (Acacia)	0.76	26	9.66	P	20%
Acacia other species (Acacia)	0.76	8.5	6.43	P	20%
Agathis multiple species	0.44	20	8.80	L + F	40%
Albizzia multiple species	0.58	19	11.02	A + F	15%
Bambusae (Bamboo)	0.35	3.5	1.23	A + F	15%
Casuarina multiple species (Mokumaou)	0.84	5	4.20	L + F	40%
Cocos nucifera (Coconut palm)	0.58	3.33	1.93	L + F	40%
Eucalyptus grandis (Eucalyptus)	0.49	24	11.76	P	20%
Eucalyptus other species (Eucalyptus)	0.49	14.5	7.11	P	20%
Gmelina arborea	0.43	19	8.17	L + F	40%
Hevea brasiliensis (Rubber)	0.53	15	7.95	L + F	40%
Leucaena leucocephala (Ipil-Ipil)	0.64	10.5	6.72	A + F	15%
Manglietia conifera	0.57	5	2.85	L + F	40%
Melaluca cajuputi	0.57	3.5	2.00	L + F	40%
Melia azedarach (Neem)	0.40	6.5	2.60	L + F	40%
Paraserianthes falcataria	0.57	33	18.81	P	20%
Pinus caribaea	0.48	19	9.12	P	20%
Pinus kesiya	0.49	12.5	6.16	P	20%
Pinus merkusii	0.54	8	4.32	L + F	40%
Pinus other species	0.49	13	6.40	P	20%
Pterocarpus indicus	0.52	12.5	6.50	L + F	40%
Rhizophora apiculata (Mangrove)	0.57	3.5	2.00	P	20%
Styrax tonkinensis	0.57	7.5	4.28	P	20%
Swietenia macrophylla (Mahogany)	0.51	7.5	3.83	L + F	40%
Tectona grandis (Teak)	0.53	8	4.20	L + F	40%
Other wood species	0.57	mix	6.72	mix	29%

Table F-2 Wood plantation area by species and country (thousand hectares)

Wood plantation areas for different crops, shown below, can be multiplied by the annual sustainable increment in tonnes per hectare from Table F-1 to estimate the annual biomass increment, in Table F-3.

The plantation area of bamboo is taken from FAO (2007); of coconut, rubber and teak (as of 2005) from the United Nations (undated); of other species in Thailand (as of 2001) from Barney (2004); and of other species in Indonesia, Malaysia, Philippines and Viet Nam (as of 2005) from FAO (2006b).

Species	Indonesia	Malaysia	Philippines	Thailand	Viet Nam
Acacia mangium (Acacia)	884	1 218	15	0	0
Acacia other species (Acacia)	238	0	15	100	287
Agathis multiple species	102	0	0	0	0
Albizzia multiple species	34	0	0	0	0
Bambusae (Bamboo)	2 081	677	172	261	813
Casuarina multiple species (Mokumaou)	0	0	0	100	0
Cocos nucifera (Coconut palm)	2 710	175	2 343	265	132
Eucalyptus grandis (Eucalyptus)	0	113	0	0	0
Eucalyptus other species (Eucalyptus)	34	0	0	446	584
Gmelina arborea	0	39	122	0	0
Hevea brasiliensis (Rubber)	3 279	1 237	82	1 692	483
Leucaena leucocephala (Ipil-Ipil)	0	0	15	0	0
Manglietia conifera	0	0	0	0	84
Melaluca cajuputi	0	0	0	0	253
Melia azedarach (Neem)	0	13	0	0	13
Paraserianthes falcataria	34	74	30	0	0
Pinus caribaea	0	35	0	0	0
Pinus kesiya	0	0	15	0	0
Pinus merkusii	680	0	0	0	0
Pinus other species	0	0	0	700	183
Pterocarpus indicus	0	0	15	0	0
Rhizophora apiculata (Mangrove)	0	0	0	0	66
Styrax tonkinensis	0	0	0	0	109
Swietenia macrophylla (Mahogany)	102	0	15	0	0
Tectona grandis (Teak)	1 258	25	0	850	30
Other wood species	34	38	61	600	104
TOTAL	**11 469**	**3 643**	**2 900**	**5 014**	**3 141**

Table F-3 Woody biomass increment by species and country (thousand tonnes per year)

Annual woody biomass increment by crop and country is found by multiplying the annual sustainable increment in tonnes per hectare from Table F-1 by plantation areas in thousand hectares from Table F-2.

Species	Indonesia	Malaysia	Philippines	Thailand	Viet Nam
Acacia mangium (Acacia)	17 371	23 931	295	0	0
Acacia other species (Acacia)	1 529	0	96	643	1 844
Agathis multiple species	897	0	0	0	0
Albizzia multiple species	375	0	0	0	0
Bambusae (Bamboo)	2 549	829	211	320	996
Casuarina multiple species (Mokumaou)	0	0	0	420	0
Cocos nucifera (Coconut palm)	5 239	338	4 530	512	255
Eucalyptus grandis (Eucalyptus)	0	1 332	0	0	0
Eucalyptus other species (Eucalyptus)	241	0	0	3 172	4 149
Gmelina arborea	0	321	997	0	0
Hevea brasiliensis (Rubber)	26 068	9 834	652	13 451	3 840
Leucaena leucocephala (Ipil-Ipil)	0	0	101	0	0
Manglietia conifera	0	0	0	0	239
Melaluca cajuputi	0	0	0	0	505
Melia azedarach (Neem)	0	33	0	0	34
Paraserianthes falcataria	639	1 391	564	0	0
Pinus caribaea	0	316	0	0	0
Pinus kesiya	0	0	92	0	0
Pinus merkusii	2 937	0	0	0	0
Pinus other species	0	0	0	4 482	1 172
Pterocarpus indicus	0	0	98	0	0
Rhizophora apiculata (Mangrove)	0	0	0	0	132
Styrax tonkinensis	0	0	0	0	466
Swietenia macrophylla (Mahogany)	390	0	57	0	0
Tectona grandis (Teak)	5 282	106	0	3 570	126
Other wood species	228	254	410	4 032	699
TOTAL	**63 746**	**38 685**	**8 103**	**30 602**	**14 457**

Table F-4a Energy wood potential by species and country (thousand tonnes per year)

Energy wood potential per annum, in thousand tonnes, is found by multiplying annual woody biomass increment by crop and country from Table F-3 by energy wood share of total wood from Table F-1.

Species	Indonesia	Malaysia	Philippines	Thailand	Viet Nam
Acacia mangium (Acacia)	3 474	4 786	59	0	0
Acacia other species (Acacia)	306	0	19	129	369
Agathis multiple species	359	0	0	0	0
Albizzia multiple species	56	0	0	0	0
Bambusae (Bamboo)	382	124	32	48	149
Casuarina multiple species (Mokumaou)	0	0	0	168	0
Cocos nucifera (Coconut palm)	2 096	135	1 812	205	102
Eucalyptus grandis (Eucalyptus)	0	266	0	0	0
Eucalyptus other species (Eucalyptus)	48	0	0	634	830
Gmelina arborea	0	129	399	0	0
Hevea brasiliensis (Rubber)	10 427	3 934	261	5 381	1 536
Leucaena leucocephala (Ipil-Ipil)	0	0	15	0	0
Manglietia conifera	0	0	0	0	96
Melaluca cajuputi	0	0	0	0	202
Melia azedarach (Neem)	0	13	0	0	14
Paraserianthes falcataria	128	278	113	0	0
Pinus caribaea	0	63	0	0	0
Pinus kesiya	0	0	18	0	0
Pinus merkusii	1 175	0	0	0	0
Pinus other species	0	0	0	896	234
Pterocarpus indicus	0	0	39	0	0
Rhizophora apiculata (Mangrove)	0	0	0	0	26
Styrax tonkinensis	0	0	0	0	93
Swietenia macrophylla (Mahogany)	156	0	23	0	0
Tectona grandis (Teak)	2 113	42	0	1 428	50
Other wood species	66	74	119	1169	203
TOTAL	**20 786**	**9 845**	**2 909**	**10 058**	**3 904**

Table F-4b Energy wood potential by species and country (Petajoules)

The energy wood potential per annum, in PJ, is found by multiplying the potential in thousand tonnes from Table F-4a by a standard factor of 19 GJ per tonne (1 PJ is 1 million GJ).

Species	Indonesia	Malaysia	Philippines	Thailand	Viet Nam
Acacia mangium (Acacia)	66.0	90.9	1.1	0	0
Acacia other species (Acacia)	5.8	0	0.4	2.4	7.0
Agathis multiple species	6.8	0	0	0	0
Albizzia multiple species	1.1	0	0	0	0
Bambusae (Bamboo)	7.3	2.4	0.6	0.9	2.8
Casuarina multiple species (Mokumaou)	0	0	0	3.2	0
Cocos nucifera (Coconut palm)	39.8	2.6	34.4	3.9	1.9
Eucalyptus grandis (Eucalyptus)	0	5.1	0	0	0
Eucalyptus other species (Eucalyptus)	0.9	0	0	12.1	15.8
Gmelina arborea	0	2.4	7.6	0	0
Hevea brasiliensis (Rubber)	198.1	74.7	5.0	102.2	29.2
Leucaena leucocephala (Ipil-Ipil)	0	0	0.3	0	0
Manglietia conifera	0	0	0	0	1.8
Melaluca cajuputi	0	0	0	0	3.8
Melia azedarach (Neem)	0	0.3	0	0	0.3
Paraserianthes falcataria	2.4	5.3	2.1	0	0
Pinus caribaea	0	1.2	0	0	0
Pinus kesiya	0	0	0.3	0	0
Pinus merkusii	22.3	0	0	0	0
Pinus other species	0	0	0	17.0	4.5
Pterocarpus indicus	0	0	0.7	0	0
Rhizophora apiculata (Mangrove)	0	0	0	0	0.5
Styrax tonkinensis	0	0	0	0	1.8
Swietenia macrophylla (Mahogany)	3.0	0	0.4	0	0
Tectona grandis (Teak)	40.1	0.8	0	27.1	1.0
Other wood species	1.3	1.4	2.3	22.2	3.9
TOTAL	**395**	**187**	**55**	**191**	**74**

Table F-5 Summary of wood energy calculations for five countries combined

This table combines (sums up) the values from the preceding tables for the five countries studied.

Species	Planted Area (Thousand Hectares)	Total Wood (Thousand Tonnes per Year)	Energy Wood (Thousand Tonnes per Year)	Energy Potential (Petajoules per Year)
Acacia mangium (Acacia)	2 117	41 597	8 319	158.1
Acacia other species (Acacia)	640	4 112	822	15.6
Agathis multiple species	102	897	359	6.8
Albizzia multiple species	34	375	56	1.1
Bambusae (Bamboo)	4 004	4 905	736	14.0
Casuarina multiple species (Mokumaou)	100	420	168	3.2
Cocos nucifera (Coconut palm)	5 625	10 874	4 350	82.6
Eucalyptus grandis (Eucalyptus)	113	1 332	266	5.1
Eucalyptus other species (Eucalyptus)	1 064	7 562	1 512	28.7
Gmelina arborea	161	1 318	527	10.0
Hevea brasiliensis (Rubber)	6 773	53 845	21 538	409.2
Leucaena leucocephala (Ipil-Ipil)	15	101	15	0.3
Manglietia conifera	84	239	96	1.8
Melaluca cajuputi	253	505	202	3.8
Melia azedarach (Neem)	26	67	27	0.5
Paraserianthes falcataria	138	2 594	519	9.9
Pinus caribaea	35	316	63	1.2
Pinus kesiya	15	92	18	0.3
Pinus merkusii	680	2 937	1 175	22.3
Pinus other species	883	5 654	1 131	21.5
Pterocarpus indicus	15	98	39	0.7
Rhizophora apiculata (Mangrove)	66	132	26	0.5
Styrax tonkinensis	109	466	93	1.8
Swietenia macrophylla (Mahogany)	117	447	179	3.4
Tectona grandis (Teak)	2 163	9 084	3 634	69.0
Other wood species	837	5 623	1 631	31.0
TOTAL	**26 169**	**155 592**	**47 502**	**903**

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