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AEMO 100% Renewable Energy Study

Potential for electricity generation in Australia from biomass in 2010, 2030 and 2050

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Important disclaimer

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Executive summary

In July 2012, CSIRO was contracted by Australian Energy Market Operator (AEMO) to provide information on renewable energy supply and electricity generation opportunities for the East coast of Australia. CSIRO was asked by AEMO to investigate a subset of technologies, and AEMO contracted other organisations to investigate other technologies.

The information supplied to AEMO will be used by AEMO as part of a “100% renewable supply” project that the Federal Government has requested AEMO to undertake.

This report was commissioned by AEMO to inform their modelling of electricity generation scenarios where renewable energy provides 100 percent of the primary energy resource. This report outlines the potential of biomass to contribute to the supply of renewable energy to the electricity sector and is one of several reports contributed by CSIRO to the AEMO study.

The potential contribution to electricity generation in 2010, 2030 and 2030 has been estimated for the following types of biomass resources:

- wood (pulp logs, in-field woody harvest residues, and processing residues) from plantations and native forests
- wood from newly established tree crops that are managed on short rotations (SRT)
- crop residues (stubble)
- residue remaining after processing of sugar cane (bagasse)
- grasses that could be harvested for bioenergy
- Municipal Solid Waste (MSW), Construction and Demolition (C&D) and Commercial and Industrial (C&I) wastes that contain mainly organic materials, but also other materials such as plastic that could be combusted.

The focus of this report is on estimating the amounts of biomass that could be potentially available - constraints imposed by the logistics of harvest, storage and transport, or by economics have not been applied, and are only briefly discussed in this report.

Due to expected new tree crop plantings, potentially available biomass increases from about 68 Mt/yr currently, to about 96 Mt/yr in 2050. Electricity generation that could be derived from this feedstock increases from about 85 to 125 TWh/yr over the same period. The contribution of various biomass types varies regionally, and over time as new biomass sources are established. In some AEMO regions near to major population centres, electricity generation potential is currently 5-10 TWh/yr, increasing to 10-17 TWh/yr by 2050.

Whilst biomass has the potential to contribute significantly to direct baseload electricity generation in some regions, it may play a more important role as an energy storage medium coupled with other renewable energy sources, thus facilitating a stable supply of renewable electricity.

Shortened forms

3PG	Physiological Principles Predicting Growth (generalised forest model)
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ACT	Australian Capital Territory
AEMO	Australian Energy Market Operator
BRS	Bureau of Resource Sciences
C&D	Construction and Demolition
C&I	Commercial and Industrial
CC	Creative Commons
CSIRO	Commonwealth Scientific and Industrial Research Organisation
GJ/t	Giga-joules per tonne
Kt	Kilo-tonne
Mha	Million hectares
MIS	Managed Investment Schemes
MSW	Municipal Solid Waste
Mt/yr	Mega-tonnes per year
NE	North-east
NF	Native forests
NPI	National Plantation Inventory
NPP	Net primary production
NSW	New South Wales
PAfH	Potentially available for harvest
Qld	Queensland
SA	South Australia
SD	Statistical Division
SE	south east
SLA	ABS Statistical Local Area
SRT	Short rotation trees
t	Tonne
t/ha	Tonnes per hectare
Tas	Tasmania
TWh	Terawatt hours
TWh/yr	Terawatt hours per year
Vic	Victoria

1 Introduction

1.1 Background

The energy contained in plant biomass is one potential source of renewable electricity production in Australia (e.g. Farine et al., 2011). There are several types of biomass produced in Australia, for which significant quantities could be available for production of bio-electricity:

- wood (pulp logs, in-field woody harvest residues, and processing residues) from plantations and native forests
- wood from newly established tree crops that are managed on short rotations (SRT)
- crop residues (stubble)
- residue remaining after processing of sugar cane (bagasse)
- grasses that could be harvested for bioenergy
- Municipal Solid Waste (MSW), Construction and Demolition (C&D) and Commercial and Industrial (C&I) wastes that contain mainly organic materials, but also other materials such as plastic that could be combusted

In the following sections we expand upon the analysis provided by Farine et al. (2011) by including additional biomass types, extended time-frames, and by providing a spatial disaggregation of biomass estimates into regions (polygons) provided by AEMO (hereafter referred to as “AEMO regions” – see Figure 4). We provide estimates of the amount of biomass available annually in 2010, 2030 and 2050 for each biomass type, within each of the AEMO regions. We also demonstrate and discuss the considerable year to year variability caused by climate (potential anthropogenic climate change is not considered here), over a 20–30 year period, in the availability of crop residues (stubble) and grass biomass. Biomass types were summed for each region and converted to the amount of electricity that could be generated assuming use of direct combustion/steam turbine technology.

This report provides estimates of potentially available biomass under the assumptions described in Section 2. The report does not examine the logistics of harvest, storage and transport of biomass or the costs of supplying biomass to power plants. Clearly there are major challenges in developing biomass supply systems at the scale required to make a major contribution to a 100% renewable electricity target.

2 Methods used to estimate available biomass from a range of sources in 2010, 2030 and 2050

For each of the biomass types, we made spatial estimates for the amounts potentially available in each of the AEMO regions. These analyses were conducted using ArcGIS, R, and Kepler. Specific details are provided under each biomass category.

2.1 Pulp logs, harvest residues and sawmill residues from plantations

The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) publication 'Australia's plantation log supply 2010–2054' (Gavran et al., 2012) was used as a basis to forecast pulp log and sawlog supply (volumes) for hardwood and softwood plantations for each National Plantation Inventory (NPI) region on an annual basis for 5 year periods. The following 3 periods were taken to approximate log flow for the 3 time periods used in this study: Period 2010–14 = 2010, Period 2030–34 = 2030, Period 2050–54 = 2050. Volumes were converted to dry mass as described in Farine et al. (2011). Using a Bureau of Resource Sciences[1] (BRS) map of forest plantation area at 1 km resolution, the area of hardwood and softwood plantation was estimated for each NPI region. This was used to estimate the average rate of wood supply /unit area for each NPI by forest type.

In-field woody residues that could be recovered for energy were calculated as 9% of harvested log mass, but all other residue components were retained in the forest for environmental reasons (Farine et al., 2011). Sawmill residues were calculated as a fraction (range 57.4 – 67.4%) of the mass of sawlogs processed, based on industry surveys (Farine et al., 2011).

The AEMO regions were overlaid on the spatial plantation data and the biomass components (pulp log, sawmill residue, woody in-field harvest residue) allocated according to those boundaries, thus providing estimates of total plantation biomass available in each AEMO region. The availability of biomass for bio-electricity was taken as 100% of pulp log, sawmill residue and in-field woody residue.

2.2 Pulp logs, in-field woody residues and sawmill residues from native forests (NF) managed for sawlog production

The following procedures were used to estimate the amount of potentially available biomass in each AEMO region:

- A BRS map of production native forests (BRS land use of Australia, version 4, 2005_06 layer; BRS, 2010), was overlaid with the AEMO regions. This showed that the major production native forests are distributed within relatively few regions in mainland south east (SE) Australia, SE Queensland, south west (SW) of Western Australia and Tasmania.
- We applied our broad knowledge of forest management, and findings from other regional studies (Rodriguez et al., 2011), to approximately allocate state-level ABARES estimates of the annual volumes

[1] Now formerly merged with ABARES, however many of the maps and publications listed here were published under its previous name.

of sawlog and pulpwood harvest from native forests to each AEMO region. Volumes were converted to dry wood mass (Farine et al., 2011).

- The total amount of available biomass in each AEMO region was taken as 100% of pulp log harvest plus 100% of sawmill residue (state based values ranged from 59 to 67% of sawlog harvest) plus ‘residual’ logs and other woody in-field residue (estimated as 60% of harvested logs) felled as a part of normal harvesting operations, but which for several reasons (e.g. they contain decayed wood) are normally non-commercial. All other harvest residues are retained in the forest. For more detailed methods see Farine et al. (2011) and Rodriguez et al. (2011).
- We assumed that the amounts of biomass available in 2010 will remain the same until 2050.

2.3 Biomass from new plantings of short rotation trees (SRT)

There is the potential to establish significant areas of new woody plantings, integrated with traditional agriculture, for production of biomass for bioenergy. Such plantings would be grown on short (< 10 years) rotations, and would often utilise coppicing (re-sprouting) species. We examined the following expansion scenario: planting of 5% of cleared farmland (~ 2.4 Mha) by 2030, and extension of the area to 10% (~ 4.8 Mha) by 2050.

Biomass production was estimated spatially using the Physiological Principles Predicting Growth (3PG) model that has been calibrated for relevant SRT species. The scenario used a stocking rate of 2500 stems/ha and a rotation length of 5 years. The location of suitable land with mean annual rainfall > 275 mm/yr was identified in the crop and sown pasture lands from the 1 km resolution BRS land use of Australia, version 4, 2005_06 layer (BRS, 2010). Further details of the methods used are described in Farine et al. (2011).

Annual biomass production in each AEMO region was calculated by cutting the spatial layer of modelled production according to the relevant boundaries.

2.4 Bagasse produced from sugar cane

Bagasse is the residue remaining after the crushing of wet cane and extraction of sugar. The bagasse volume available was estimated from sugar industry production statistics for six regional reporting regions for the period 1997 to 2007 in coastal Queensland and northern New South Wales (NSW) (Anon., 1996–2007; ASMC, 1996–2007).

Wet cane yields were adjusted to account for sugar extracted, and for moisture content to estimate the amounts of dry bagasse residue produced (equivalent to ~ 15% of the weight of wet cane). The AEMO regions were overlaid on the sugar production zones, and the average total annual production of bagasse (~ 5.5 M dry t) was allocated to four relevant regions in proportion to average annual cane harvest. It was assumed that all bagasse was potentially available for electricity production. Trash remaining in the field after cane harvest was not considered to be available as an energy source.

2.5 Crop stubble

Broad acre crop residues remaining after harvest (stubble) were estimated from annual grain production statistics, and harvest index data (the ratio of grain to total above-ground biomass) (Herr et al., 2010). Estimates were made nationally at the Australian Bureau of Statistics (ABS) 2002 Statistical Division (SD) level of spatial resolution. The AEMO regions were overlaid on the cropping areas (Knapp et al. 2006) by 2002 SD. This defines the cropping area within each AEMO region and how these relate to 2002 SDs. The land use information and methods for overlaying polygons of different size/shape to transfer values are described elsewhere (Herr and Dunlop 2011; Herr 2007).

Each AEMO region was assigned a stubble production based on the proportion of land use of the intersecting 2002 SDs. The average stubble production for the period 1996-2005 was applied, noting that there is large inter-annual variability in crop yields and thus stubble production (Fig.1). Further details, including rationale for retention of some crop residue for soil protection, are provided in Herr et al. (2011) and Farine et al. (2011).

2.6 Grasses harvested for bioenergy

Grasses have not previously been assessed as potential sources of biomass for bioenergy, although Herr et al. (2012) has made broad model-based estimates of grass production across Australia. In this study we applied the model AussieGRASS[2] (Carter et al. 2000; Carter et al. 2003) to generate spatial estimates of net primary production (NPP) and of standing (potentially harvestable) biomass. Aussiegrass estimates pasture biomass, which includes native and introduced grasses and forbs. For ease of description we will refer to the estimates as grass biomass potentially available for harvest (PAfH).

The following constraints were applied to estimate the amount of dry grass biomass PAfH:

- Harvest is only possible if standing biomass is >= 5 t/ha, so that 2.5 t/ha can remain for soil protection, and at least 3 t/ha can be removed so as to make harvesting worthwhile.
- The only areas of grassland considered to be practical to harvest are where tree basal cover is < 12 % and slopes < 12 degrees.

The biomass that could be potentially harvested was calculated for each 5 km^2 pixel for each year over a period of 30 years (1981–2010), and also as an average over that period. Potentially harvestable grass was aggregated taking account of relevant areas within each AEMO region.

2.7 Waste

Waste biomass is defined as the biomass component of "…any discarded, rejected, unwanted, surplus or abandoned matter" (DEWHA 2010; p.361). The fractions of suitable biomass in the MSW, C&I and C&D waste streams were estimated by synthesising data in the National Waste Report 2010 (DEWHA 2010) and from Appendix 2 (Organics recovery by State/Sector) of Waste and Recycling in Australia (Hyder Consulting 2009). The quantities of waste in each AEMO region were estimated from population distribution, and the average amount of waste generated per person. There were three steps involved:

1. Estimate the current and future population in each AEMO region

   Using the GIS we intersected AEMO region with ABS Statistical Local Area (SLA; as at 2006 Census) and ABS 2006 Mesh Blocks (parts of SLAs). On the basis of percentage-area within each AEMO region basis we apportioned the mesh block population. These populations were aggregated at the SLA level, then divided by total SLA population to determine the percentage of SLA population within each AEMO region

   It was assumed that each SLA would contribute a constant percentage of its population to overlapping AEMO regions through to 2050. This percentage is based on the current proportion of an SLA's total population in the collected populated meshblock areas within particular AEMO regions. Estimates of SLA current (2007) and future (2030, 2050) population were obtained from scenarios developed by Baynes (2012, unpublished), based on ABS projections 2006–2100. Each population estimate was multiplied by the SLA population fraction per AEMO region to determine the AEMO region population for each of the three time horizons. These data are provided at Appendix 1.

2. Estimate waste generation Per-Capita

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[2] See http://www.longpaddock.qld.gov.au/about/researchprojects/aussiegrass/index.html

We aggregated data extracted from Hyder Consulting (2009) and DEWHA (2010) about the mass of components of the three waste streams in each state that could be considered suitable for conversion to bioenergy, regardless of whether recycled or put into landfill. These amounts of biomass were then divided by current state population to calculate waste generation per capita. Data gaps for some states meant that the some potential resources are not included in this study.

3. Estimate the total Waste Biomass in each AEMO region

We selected the Australian state in which each AEMO region is mostly or entirely located, and then multiplied the number of people in each region by the per capita waste generation for the relevant state to estimate total waste generation. We have not attempted to convert the reported mass of each type of waste to dry weights, because of a lack of data on moisture content for the various waste fractions.

3 Conversion of biomass to electricity

The energy content in dry biomass generally varies from about 17–21 GJ/t (Jenkins et.al., 1998; Demirbas, 2001), with high lignin contents causing higher values. In our calculations we have assumed an energy content of 19 GJ/t, a value that has been reported for crop straw, grass, bagasse, 'waste' and wood. AEMO have specified that biomass can be converted to electricity using direct combustion/steam turbine technology with efficiencies of 22% for bagasse, and 27% for other solid biomass materials. We applied a conversion efficiency of 22% to crop residues, grasses and bagasse; and 27% to waste and all wood fuels. Under a future scenario in which there is strong progress on lowering technology costs (for details see http://www.climatechange.gov.au/government/initiatives/aemo-100-per-cent-renewables/aemo-scoping-document.aspx), we assumed the efficiency of biomass conversion to electricity using the above technology might increase by 10% (to 24.2% and 29.7%, respectively) by 2050. We note that higher efficiencies of conversion are already possible using other technologies.

Thus, using current efficiencies 1 t dry crop residue, grass or bagasse can generate 1.162 MWh of electricity, and thus 0.861 Mt of biomass is required to generate 1 TWh of electricity. For woody fuels, 1 t biomass can generate 1.426 MWh of electricity, and thus 0.701 Mt of biomass is required to generate 1 TWh of electricity.

The electricity calculations presented in Tables 5 to 9 and Figures 4 to 6 are expressed as TWh produced annually. For biomass it is possible to produce electricity at a constant rate throughout the year or day, or to vary it throughout the year or day (within the limits imposed by biomass supply logistics, and conversion capacity and plant response times) to help stabilize electricity supply by supplementing the intermittent sources from other renewable energy sources such as solar and wind.

4 Key results

4.1 Plantations

The amount of biomass potentially available from plantations ranges from about 8 to 10 Mt/yr over the period 2010–2050 (Tables 2-4). This assumes the area of plantations will change little over that time frame (Gavran et al., 2012). High availabilities (> 1 Mt/yr) are confined to about 4 regions for 2010 and 6 regions for 2030 and 2050. The total amount of electricity that could be generated ranges from about 12 to 16 TWh/yr (Tables 5–7), and between regions this ranges from zero to 2.8 TWh/yr.

4.2 Native forests

The amount of biomass potentially available from native forests managed for wood production is about 7.3 Mt/yr, and is assumed to remain constant over time (Tables 2–4). This translates into production of 10.4 TWh/yr of electricity (Table 5). There are 6 AEMO regions with potential production of > 0.5 TWh/yr, and 3 regions with potential for > 1.6 TWh/yr.

4.3 Short rotation trees (SRT)

There is negligible biomass currently available from SRT crops, but this could increase to about 10 Mt/yr by 2030 and to 20 Mt/yr by 2050 (Tables 2-4). Distribution is quite widespread across the major agricultural production zones. Total electricity production could be about 14.5 TWh/yr by 2030 and 29 TWh/yr by 2050 (Tables 5–7). By 2050, 8 AEMO regions would have potential for generation of > 1.3 TWh/yr and 2 regions have the potential to produce > 4 TWh/yr.

4.4 Bagasse

It is estimated that there are 5.5 Mt/yr of bagasse potentially available for electricity production (Table 2), and this is assumed to remain constant over time. This translates to generation of 6.4 TWh/yr of electricity (Table 5), distributed across 5 AEMO regions in coastal Queensland and north-east (NE) NSW. There are two regions with potential electricity generation of 2–3 TWh/yr.

4.5 Crop stubble

As shown in the Fig. 1 (from Herr et al., 2011) there is large annual variation in the amount of stubble available for harvest that correlates broadly with annual variation in rainfall. Variation across the time series examined was nearly two-fold, with national total availability ranging from about 15–35 Mt/yr. On average, within the AEMO regions, about 18 Mt/yr of stubble is potentially available for electricity generation, and this assumed to remain constant over time (Tables 2–4). The average amount of stubble translates to generation of about 20 TWh/yr of electricity. There are 8 regions with the potential to generate > 1 TWh/yr, and 3 regions with potential of 2–3 TWh/yr.

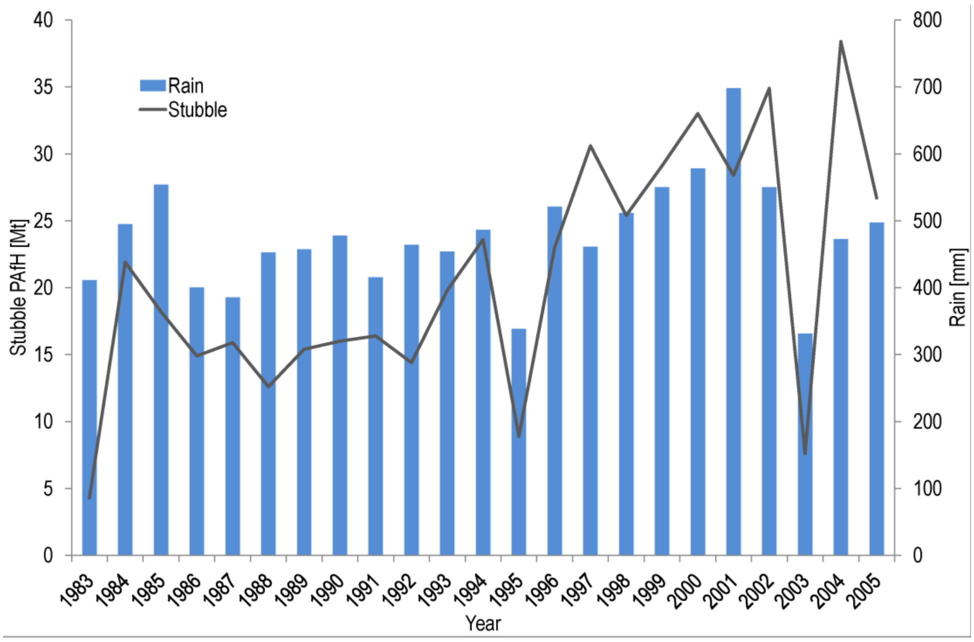

Figure 1. Variation in annual rainfall, and the amount of stubble potentially available for harvest (PAfH) across Australia for the period 1983–2005 (from Herr et al. 2011).

4.6 Grasses

There was extremely high inter-annual variability in the amount of grass biomass PAfH for bioenergy (Fig. 2). Across a 30-year period modelled, the amount varied from about 1 to 95 Mt/yr. The mean annual availability was about 20 Mt (with a standard deviation of 22 Mt). Variation in the production correlates highly with the area of production. Figure 3 shows the areas where available grass biomass is concentrated in years of widely varying total production.

Using the average annual availability of biomass, distribution across AEMO regions, which is assumed to be constant over time, is shown in Tables 2–4. These amounts translate into total electricity production of about 23 TWh/yr. Distribution is widespread. There are 12 regions where potential for electricity generation is approximately 1 TWh/yr or more.

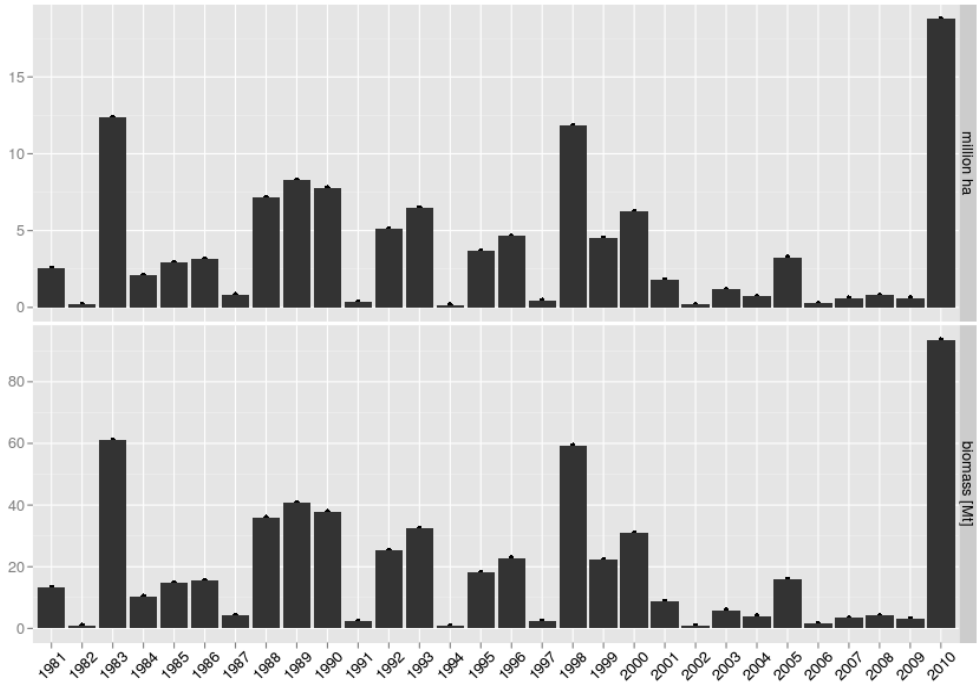

Figure 2. Inter-annual variation in harvestable grass area and grass biomass potentially available for harvest (PAfH) over the period 1981–2010.

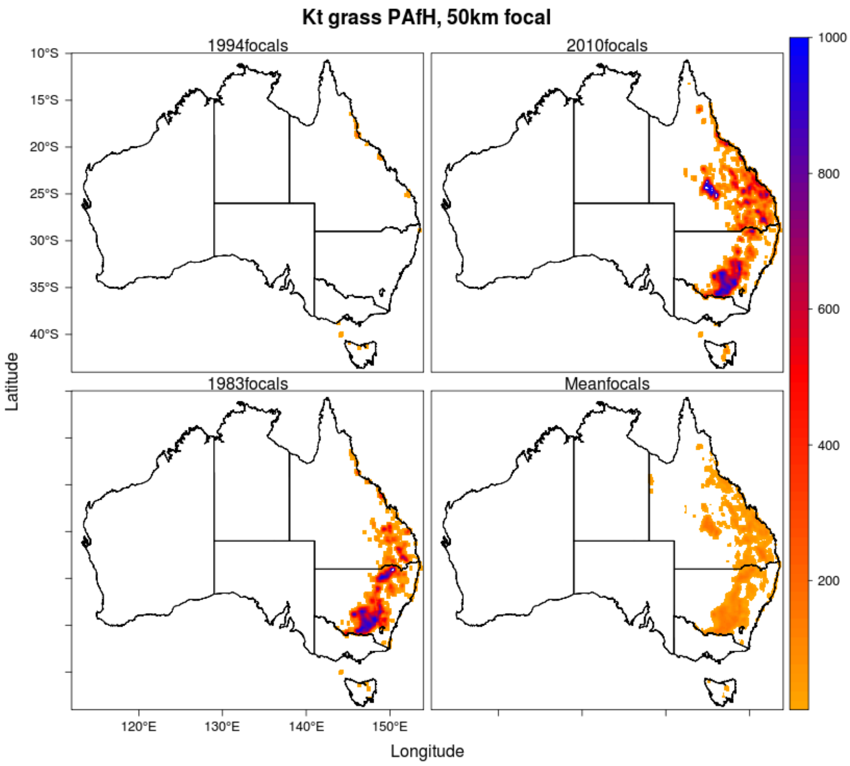

Figure 3. Grass biomass (kt) focal concentrations (potentially available for harvest (PAfH) within approximately 50km radius) that visually highlight areas of high production for the lowest, highest, second highest and average year over the period 1981–2010.

4.7 Waste

The annual amount of suitable waste biomass per-capita is shown in Table 1. The variation between states is dependent on available data about the amounts and components of the MSW, C&I and C&D waste streams.

The amount of waste potentially available for electricity generation is estimated to increase from about 9.2 Mt/yr currently to about 14.7 Mt/yr by 2050 (Table 2–4). This translates to production of about 13–21 TWh/yr over the same time period. Potential is greatest (> 1.5 TWh/yr) in 4 AEMO regions where population is highest.

Table 1. Rates of waste biomass per-capita generated in each state.

STATE	WASTE BIOMASS (t/person/yr)
New South Wales (NSW)	0.383
Queensland (Qld)	0.486
South Australia (SA)	0.683
Tasmania (Tas)	0.097
Victoria (Vic)	0.644
Australian Capital Territory (ACT)	1.150

Source: CSIRO analysis of published waste data

Table 2. Biomass potentially available (kt/yr) from 7 sources for electricity production in 42 AEMO regions at 2010.

AEMO REGION	BAGASSE	NATIVE FOREST	PASTURE GRASS	PLANTATION FOREST	SHORT-ROTATION TREES	STUBBLE	WASTE BIOMASS	TOTAL BIOMASS (kt/yr)
1	1729	0	297	52	0	1	121	2200
2	0	0	0	0	0	0	2	2
3	0	0	203	0	0	0	1	204
4	2610	0	942	3	0	13	172	3740
5	0	0	46	0	0	0	2	48
6	0	0	787	0	0	52	14	853
7	0	29	1317	44	0	41	93	1525
8	0	0	0	0	0	0	0	0
9	0	0	1733	0	0	0	2	1735
10	0	0	949	0	0	74	3	1025
11	204	58	943	295	0	19	97	1617
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	26	0	0	0	3	30
16	0	0	1211	0	0	683	17	1911
17	613	204	1426	458	0	435	1605	4741
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	4	4
20	0	0	0	0	0	0	1	1
21	0	0	0	0	0	0	0	1
22	0	0	0	0	0	21	4	25
23	0	0	1923	0	0	1422	20	3366
24	350	722	826	171	0	622	191	2881
25	0	0	0	0	0	295	4	299
26	0	0	0	38	0	1859	63	1960
27	0	0	0	19	0	1044	28	1091
28	0	0	0	0	0	20	8	28
29	0	0	385	0	0	474	2	861
30	0	0	2216	0	0	1694	37	3948
31	0	289	807	501	0	205	2013	3815
32	0	0	0	1090	0	1587	980	3657
33	0	0	36	0	0	712	46	794
34	0	0	256	0	0	718	21	995
35	0	0	2198	22	0	1912	91	4223
36	0	433	843	1226	0	248	319	3070
37	0	171	7	1508	0	2641	130	4455
38	0	1536	120	1107	0	901	3145	6809
39	0	386	21	679	0	5	10	1100
40	0	1157	55	667	0	51	14	1944
41	0	0	0	23	0	0	0	24
42	0	2314	27	309	0	15	24	2689
Totals	**5506**	**7299**	**19600**	**8212**	**0**	**17764**	**9287**	**67671**

Source for all Tables: CSIRO estimates (see Section 2).

Table 3. Biomass potentially available (kt/yr) from 7 sources for electricity production in 42 AEMO regions at 2030.

AEMO REGION	BAGASSE	NATIVE FOREST	PASTURE GRASS	PLANTATION FOREST	SHORT-ROTATION TREES	STUBBLE	WASTE BIOMASS	TOTAL BIOMASS (kt/yr)
1	1729	0	297	98	119	1	177	2422
2	0	0	0	0	0	0	2	2
3	0	0	203	0	0	0	1	204
4	2610	0	942	15	103	13	261	3944
5	0	0	46	0	1	0	2	49
6	0	0	787	0	131	52	20	990
7	0	29	1317	108	121	41	135	1751
8	0	0	0	0	0	0	0	0
9	0	0	1733	0	1	0	2	1736
10	0	0	949	0	162	74	3	1188
11	204	58	943	416	54	19	153	1846
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	26	0	2	0	3	31
16	0	0	1211	0	562	683	18	2474
17	613	204	1426	935	512	435	2480	6605
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	6	6
20	0	0	0	0	0	0	1	1
21	0	0	0	0	0	0	0	1
22	0	0	0	0	14	21	4	39
23	0	0	1923	0	636	1422	17	3998
24	350	722	826	500	237	622	231	3487
25	0	0	0	0	98	295	5	397
26	0	0	0	98	621	1859	71	2649
27	0	0	0	21	267	1044	29	1361
28	0	0	0	0	0	20	8	27
29	0	0	385	0	84	474	2	945
30	0	0	2216	0	483	1694	38	4432
31	0	289	807	485	87	205	2580	4451
32	0	0	0	1303	1233	1587	1211	5334
33	0	0	36	0	140	712	55	944
34	0	0	256	0	53	718	22	1049
35	0	0	2198	22	533	1912	110	4775
36	0	433	843	1297	145	248	400	3367
37	0	171	7	1980	1714	2641	140	6653
38	0	1536	120	1319	1630	901	4242	9747
39	0	386	21	1089	109	5	10	1620
40	0	1157	55	1045	231	51	16	2554
41	0	0	0	36	0	0	0	37
42	0	2314	27	482	111	15	28	2978
Totals	**5506**	**7299**	**19600**	**11249**	**10194**	**17764**	**12483**	**84094**

Table 4. Biomass potentially available (kt/yr) from 7 sources for electricity production in 42 AEMO regions at 2050.

AEMO REGION	BAGASSE	NATIVE FOREST	PASTURE GRASS	PLANTATION FOREST	SHORT-ROTATION TREES	STUBBLE	WASTE BIOMASS	TOTAL BIOMASS (kt/yr)
1	1729	0	297	100	239	1	232	2597
2	0	0	0	0	0	0	3	3
3	0	0	203	0	0	0	1	204
4	2610	0	942	8	206	13	339	4117
5	0	0	46	0	2	0	3	51
6	0	0	787	0	262	52	26	1127
7	0	29	1317	87	242	41	177	1892
8	0	0	0	0	0	0	0	1
9	0	0	1733	0	2	0	2	1737
10	0	0	949	0	324	74	4	1350
11	204	58	943	395	108	19	200	1926
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	26	0	3	0	4	34
16	0	0	1211	0	1124	683	23	3042
17	613	204	1426	643	1024	435	3133	7478
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	6	6
20	0	0	0	0	0	0	1	1
21	0	0	0	0	0	0	0	1
22	0	0	0	0	28	21	4	53
23	0	0	1923	0	1271	1422	20	4636
24	350	722	826	304	473	622	263	3559
25	0	0	0	0	195	295	5	495
26	0	0	0	37	1241	1859	79	3216
27	0	0	0	16	534	1044	32	1626
28	0	0	0	0	0	20	9	28
29	0	0	385	0	167	474	2	1028
30	0	0	2216	0	967	1694	43	4920
31	0	289	807	507	174	205	2936	4917
32	0	0	0	1184	2466	1587	1343	6580
33	0	0	36	0	280	712	65	1094
34	0	0	256	0	106	718	25	1106
35	0	0	2198	22	1067	1912	127	5326
36	0	433	843	1224	291	248	458	3497
37	0	171	7	1661	3429	2641	167	8075
38	0	1536	120	1403	3259	901	5002	12220
39	0	386	21	1191	218	5	10	1830
40	0	1157	55	1085	462	51	16	2826
41	0	0	0	36	1	0	0	37
42	0	2314	27	498	223	15	29	3106
Totals	**5506**	**7299**	**19600**	**10401**	**20388**	**17764**	**14789**	**95742**

Table 5. Potential electricity production (TWh/yr) at 2010 for 7 biomass types across 42 AEMO regions.

AEMO REGION	BAGASSE	NATIVE FOREST	PASTURE GRASS	PLANTATION FOREST	SHORT-ROTATION TREES	STUBBLE	WASTE BIOMASS	TOTAL ELECTRICITY (TWh/yr)
1	2.01	0	0.34	0.07	0	0	0.17	2.60
2	0	0	0	0	0	0	0	0
3	0	0	0.24	0	0	0	0	0.24
4	3.03	0	1.09	0	0	0.02	0.24	4.38
5	0	0	0.05	0	0	0	0	0.06
6	0	0	0.91	0	0	0.06	0.02	0.99
7	0	0.04	1.53	0.06	0	0.05	0.13	1.81
8	0	0	0	0	0	0	0	0
9	0	0	2.01	0	0	0	0	2.01
10	0	0	1.10	0	0	0.09	0	1.19
11	0.24	0.08	1.09	0.42	0	0.02	0.14	1.99
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0.03	0	0	0	0	0.04
16	0	0	1.40	0	0	0.79	0.02	2.22
17	0.71	0.29	1.65	0.65	0	0.50	2.28	6.09
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0.01	0.01
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0.02	0.01	0.03
23	0	0	2.23	0	0	1.65	0.03	3.91
24	0.41	1.02	0.96	0.24	0	0.72	0.27	3.62
25	0	0	0	0	0	0.34	0.01	0.35
26	0	0	0	0.05	0	2.16	0.09	2.30
27	0	0	0	0.03	0	1.21	0.04	1.28
28	0	0	0	0	0	0.02	0.01	0.03
29	0	0	0.45	0	0	0.55	0	1.00
30	0	0	2.57	0	0	1.97	0.05	4.59
31	0	0.41	0.94	0.71	0	0.24	2.86	5.15
32	0	0	0	1.55	0	1.84	1.39	4.78
33	0	0	0.04	0	0	0.83	0.07	0.93
34	0	0	0.30	0	0	0.83	0.03	1.16
35	0	0	2.55	0.03	0	2.22	0.13	4.93
36	0	0.61	0.98	1.74	0	0.29	0.45	4.08
37	0	0.24	0.01	2.14	0	3.06	0.18	5.64
38	0	2.18	0.14	1.57	0	1.04	4.47	9.40
39	0	0.55	0.02	0.96	0	0.01	0.01	1.56
40	0	1.64	0.06	0.95	0	0.06	0.02	2.73
41	0	0	0	0.03	0	0	0	0.03
42	0	3.29	0.03	0.44	0	0.02	0.03	3.81
Totals	**6.4**	**10.35**	**22.72**	**11.64**	**0**	**20.61**	**13.16**	**84.94**

Table 6. Potential electricity production (TWh/yr) at 2030 for 7 biomass types across 42 AEMO regions.

AEMO REGION	BAGASSE	NATIVE FOREST	PASTURE GRASS	PLANTATION FOREST	SHORT-ROTATION TREES	STUBBLE	WASTE BIOMASS	TOTAL ELECTRICITY (TWh/yr)
1	2.01	0	0.34	0.14	0.17	0	0.25	2.91
2	0	0	0	0	0	0	0	0
3	0	0	0.24	0	0	0	0	0.24
4	3.03	0	1.09	0.02	0.15	0.02	0.37	4.67
5	0	0	0.05	0	0	0	0	0.06
6	0	0	0.91	0	0.19	0.06	0.03	1.19
7	0	0.04	1.53	0.15	0.17	0.05	0.19	2.13
8	0	0	0	0	0	0	0	0
9	0	0	2.01	0	0	0	0	2.01
10	0	0	1.10	0	0.23	0.09	0	1.42
11	0.24	0.08	1.09	0.59	0.08	0.02	0.22	2.32
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0.03	0	0	0	0	0.04
16	0	0	1.40	0	0.80	0.79	0.03	3.02
17	0.71	0.29	1.65	1.33	0.73	0.50	3.52	8.74
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0.01	0.01
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0.02	0.02	0.01	0.05
23	0	0	2.23	0	0.90	1.65	0.02	4.81
24	0.41	1.02	0.96	0.71	0.34	0.72	0.33	4.48
25	0	0	0	0	0.14	0.34	0.01	0.49
26	0	0	0	0.14	0.88	2.16	0.10	3.28
27	0	0	0	0.03	0.38	1.21	0.04	1.66
28	0	0	0	0	0	0.02	0.01	0.03
29	0	0	0.45	0	0.12	0.55	0	1.12
30	0	0	2.57	0	0.69	1.97	0.05	5.28
31	0	0.41	0.94	0.69	0.12	0.24	3.66	6.06
32	0	0	0	1.85	1.75	1.84	1.72	7.16
33	0	0	0.04	0	0.20	0.83	0.08	1.15
34	0	0	0.30	0	0.08	0.83	0.03	1.24
35	0	0	2.55	0.03	0.76	2.22	0.16	5.71
36	0	0.61	0.98	1.84	0.21	0.29	0.57	4.50
37	0	0.24	0.01	2.81	2.43	3.06	0.20	8.76
38	0	2.18	0.14	1.87	2.31	1.04	6.02	13.58
39	0	0.55	0.02	1.55	0.15	0.01	0.01	2.29
40	0	1.64	0.06	1.48	0.33	0.06	0.02	3.60
41	0	0	0	0.05	0	0	0	0.05
42	0	3.29	0.03	0.68	0.16	0.02	0.04	4.22
Totals	**6.4**	**10.35**	**22.72**	**15.96**	**14.49**	**20.61**	**17.7**	**108.28**

Table 7. Potential electricity production (TWh/yr) at 2050 for 7 biomass types across 42 AEMO regions.

AEMO REGION	BAGASSE	NATIVE FOREST	PASTURE GRASS	PLANTATION FOREST	SHORT-ROTATION TREES	STUBBLE	WASTE BIOMASS	TOTAL ELECTRICITY (TWh/yr)
1	2.01	0	0.34	0.14	0.34	0	0.33	3.16
2	0	0	0	0	0	0	0	0
3	0	0	0.24	0	0	0	0	0.24
4	3.03	0	1.09	0.01	0.29	0.02	0.48	4.92
5	0	0	0.05	0	0	0	0	0.06
6	0	0	0.91	0	0.37	0.06	0.04	1.38
7	0	0.04	1.53	0.12	0.34	0.05	0.25	2.33
8	0	0	0	0	0	0	0	0
9	0	0	2.01	0	0	0	0	2.02
10	0	0	1.10	0	0.46	0.09	0.01	1.65
11	0.24	0.08	1.09	0.56	0.15	0.02	0.28	2.43
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0.03	0	0	0	0.01	0.04
16	0	0	1.40	0	1.60	0.79	0.03	3.83
17	0.71	0.29	1.65	0.91	1.45	0.50	4.45	9.98
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0.01	0.01
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0.04	0.02	0.01	0.07
23	0	0	2.23	0	1.81	1.65	0.03	5.71
24	0.41	1.02	0.96	0.43	0.67	0.72	0.37	4.59
25	0	0	0	0	0.28	0.34	0.01	0.63
26	0	0	0	0.05	1.76	2.16	0.11	4.08
27	0	0	0	0.02	0.76	1.21	0.05	2.04
28	0	0	0	0	0	0.02	0.01	0.04
29	0	0	0.45	0	0.24	0.55	0	1.24
30	0	0	2.57	0	1.37	1.97	0.06	5.97
31	0	0.41	0.94	0.72	0.25	0.24	4.17	6.72
32	0	0	0	1.68	3.50	1.84	1.91	8.93
33	0	0	0.04	0	0.40	0.83	0.09	1.36
34	0	0	0.30	0	0.15	0.83	0.04	1.32
35	0	0	2.55	0.03	1.51	2.22	0.18	6.49
36	0	0.61	0.98	1.74	0.41	0.29	0.65	4.68
37	0	0.24	0.01	2.36	4.87	3.06	0.24	10.78
38	0	2.18	0.14	1.99	4.63	1.04	7.10	17.09
39	0	0.55	0.02	1.69	0.31	0.01	0.01	2.59
40	0	1.64	0.06	1.54	0.66	0.06	0.02	3.99
41	0	0	0	0.05	0	0	0	0.05
42	0	3.29	0.03	0.71	0.32	0.02	0.04	4.40
Totals	**6.4**	**10.35**	**22.72**	**14.75**	**28.94**	**20.61**	**20.99**	**124.82**

5 The potential contribution of biomass to the objective of achieving 100% renewable electricity supply

Table 8 provides an overall summary of the potential to supply biomass and produce electricity for the three time-frames examined. Currently, potentially available biomass in the AEMO regions is considerable and could generate electricity equivalent to about 37% of national consumption, and an even higher proportion (44%) of demand in the National Electricity Market (http://www.aemo.com.au/en/Electricity/Forecasting/2012-National-Electricity-Forecasting-Report). There is potential for about a 30% growth in production of electricity from biomass in the AEMO regions to an annual production of about 125 TWh/yr by 2050. Under a scenario of 'high technological change' additional biomass is likely to be available (Table 9), but the magnitude of the increase is very uncertain.

The distribution of total potential electricity generation across the 42 AEMO regions for each of the time periods examined is provided in Tables 5–7, and displayed spatially in Figures 4–6. There is potential to generate > 1TWh/yr in most regions if existing biomass could be utilized, and there is the potential to generate more than 3 TWh/yr in many regions. All the biomass sources make a significant contribution to potential biomass availability, with stubble and grasses being the largest contributors. However these sources are the most widely distributed with low biomass density making the logistics of harvesting and transport challenging. They are also only available for harvest during part of the year, so that storage is important if they are to be fully utilized. For grasses, harvesting in the summer rainfall part of Australia (i.e. tropics) is after the wet season, from March – May. During the wet season harvesting is generally not possible due to the impact of machinery on soil. The beginning of the dry season is the ideal time for maximising harvest amounts, after this the biomass is decaying and losses increase. In the winter rain areas (Mediterranean climate) harvesting takes place as soon as there is sufficient grass biomass on the ground, and coincides with grain harvest in about November-December, or slightly earlier in the more northern zones. Hay making in the temperate zone is more varied but mainly around the Nov-Dec, when biomass is high and consecutive hot days allow cutting and drying. For harvest of 'wet' biomass (i.e. no drying required) which is useful for biogas production, timing would be similar because farmers will target harvest at optimum biomass accumulation.

A further challenge results from the considerable inter-annual variability of production of grass and stubble, especially for grasses. Woody biomass sources suffer much less from these constraints to supply and capacity for utilization, because biomass accumulates over time and can be effectively 'stored' in the field until required.

By 2030, SRT could make a significant contribution of about 15 TWh/yr, and this could be doubled by 2050. A major investment would be required to establish such a source of biomass for electricity across the agricultural production zone. Realistically, an establishment rate exceeding 100,000 ha/yr (as achieved with establishment of blue gum plantations over several years during the Managed Investment Schemes (MIS) expansion of the last decade) is unlikely. Thus it will take decades of investment to establish a large resource.

Table 8. Summary of the amounts of biomass potentially available (sum of all biomass types) and resultant potential electricity generation for 2010, 2030 and 2050.

TIME HORIZON	TOTAL BIOMASS (Mt/yr)	TOTAL ELECTRICITY (TWh/yr)	% OF AUSTRALIAN ELECTRICITY	NOTE
2010	67.6	84.9	37%	Current national consumption of 230 TWh/yr
2030	84.1	108.2		
2050	95.7	124.8		

Under a 'high technology change' scenario there are many possible changes that could either increase the amount of biomass potentially available, reduce costs of biomass supplied to plants, or improve the efficiency of electricity generation. We have captured all these in an assumption that the conversion of biomass to electricity would increase by 10% by 2050. The total electricity produced from biomass under this assumption is given in Table 9.

Table 9. Summary of the amounts of biomass potentially available (sum of all biomass types) and resultant potential electricity generation for 2010, 2030 and 2050, in a high technology scenario (+10% conversion efficiency biomass to bioenergy).

TIME HORIZON	TOTAL BIOMASS (Mt/yr)	TOTAL ELECTRICITY (TWh/yr)	% OF AUSTRALIAN ELECTRICITY	NOTE
2010	67.6	93.6	40%	Current national consumption of 230 TWh/yr
2030	84.1	119.3		
2050	95.7	137.5		

In this study, we have only included the amounts of biomass potentially available on an on-going (sustainable yield) basis. Some constraints have been applied to the amount harvestable to protect environmental values, and for forests the high value sawlog component was not considered to be available, but all pulp logs were considered to be potentially available. Organic waste resources in Australia were considered to be available, but would become a contested resource if utilised to generate electricity — at present over 51% of waste generated in Australia is recycled (DEWHA 2010). There are many other sectors that may also be future competitors for the use of biomass resources as inputs (e.g. transport fuel, carbon forestry, petrochemical).

Constraints imposed by the logistics of harvest, storage and transport, or by economics have not been applied, and are not discussed in this report. Transport costs are a major impediment to the utilization of biomass (see for example, Rodriguez et. al., 2011), as will be the logistics of effectively using large amounts of grass or crop residue which have a strongly seasonal availability. Clearly there are major challenges in developing biomass supply systems at the scale required to make a major contribution to a 100% renewable electricity target.

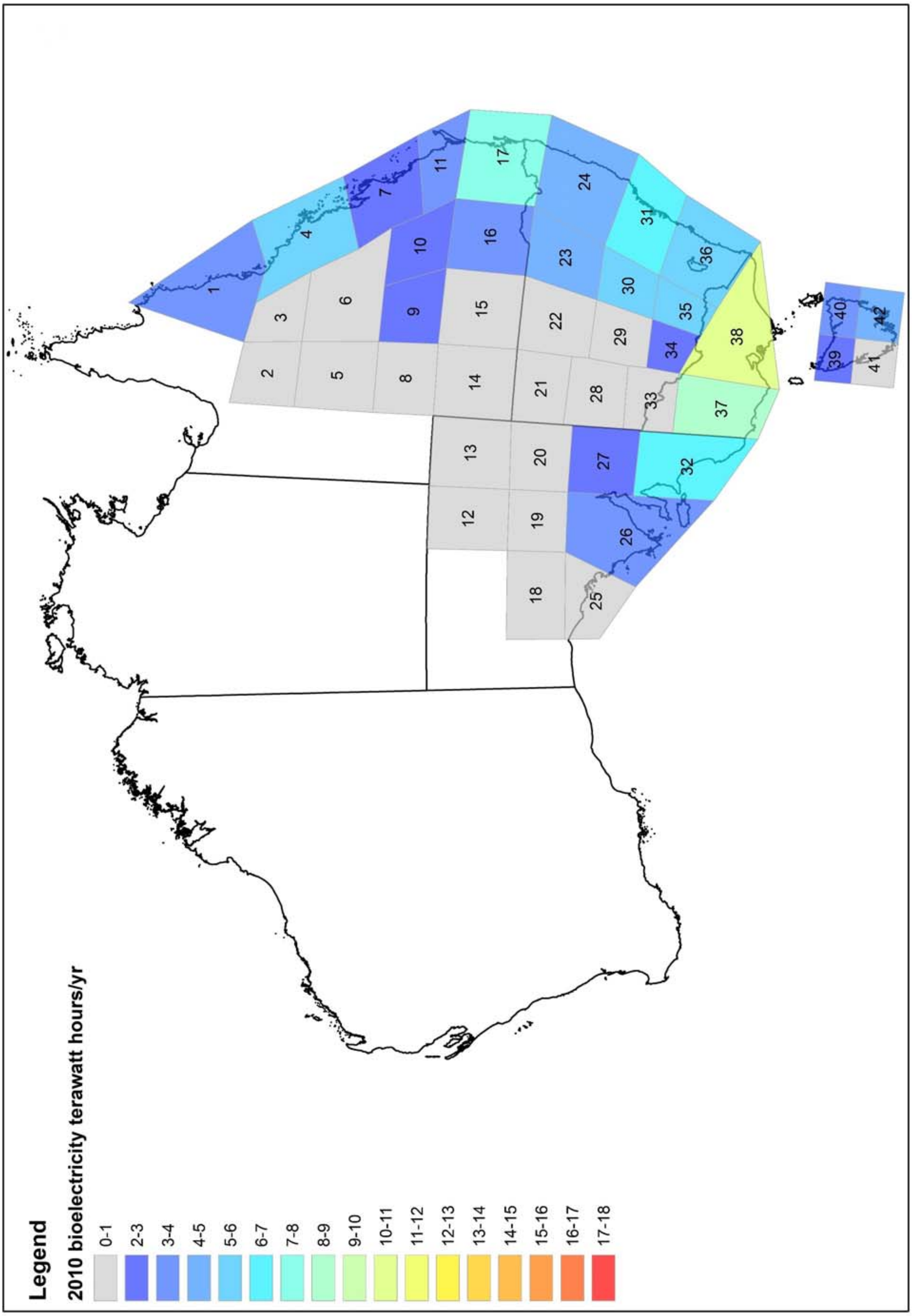

Figure 4. Spatial representation of the potential contribution of biomass to electricity generation (TWh/yr) in each of the 42 AEMO regions, period 2010.

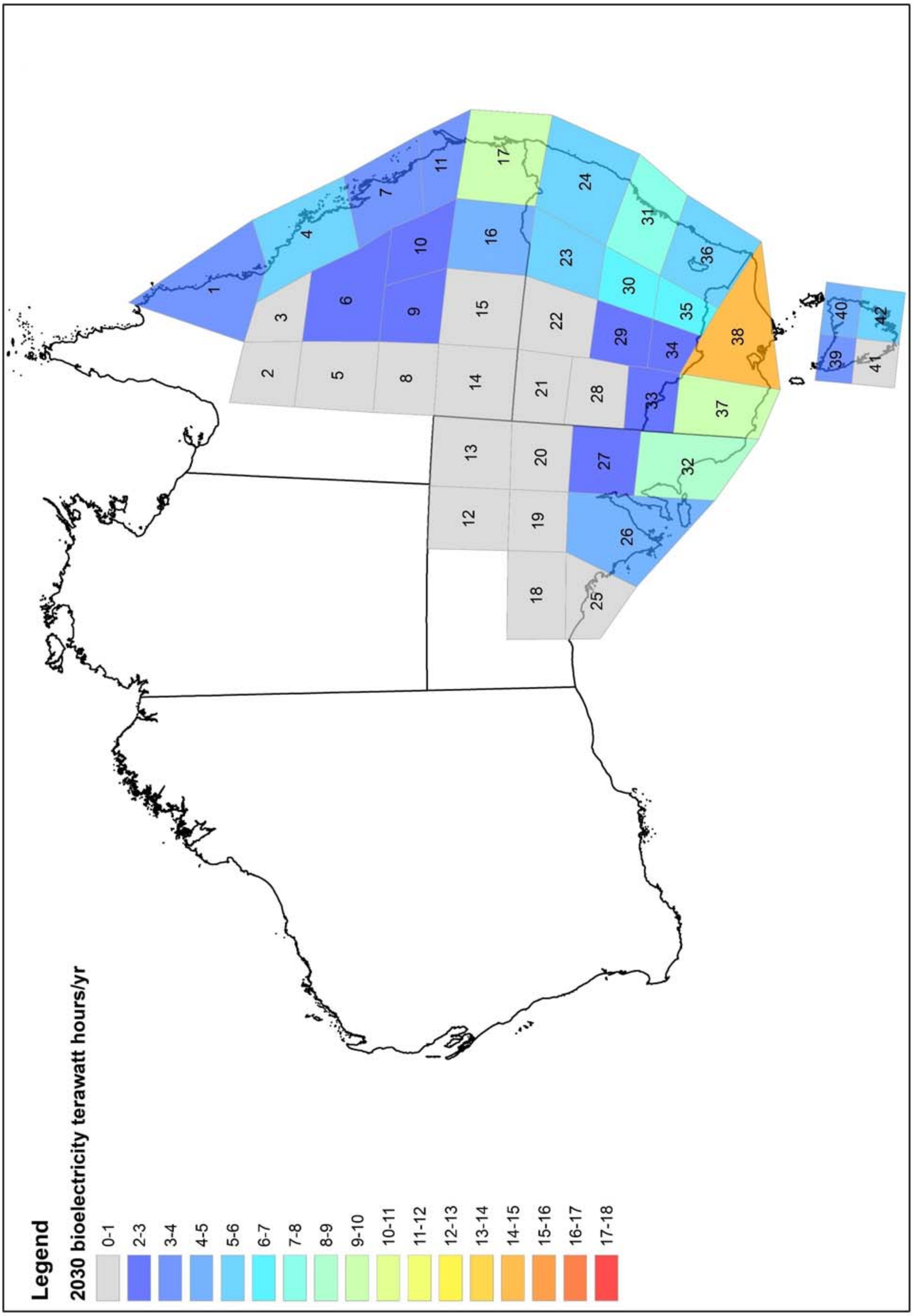

Figure 5. Spatial representation of the potential contribution of biomass to electricity generation (TWh/yr) in each of the 42 AEMO regions, period 2030.

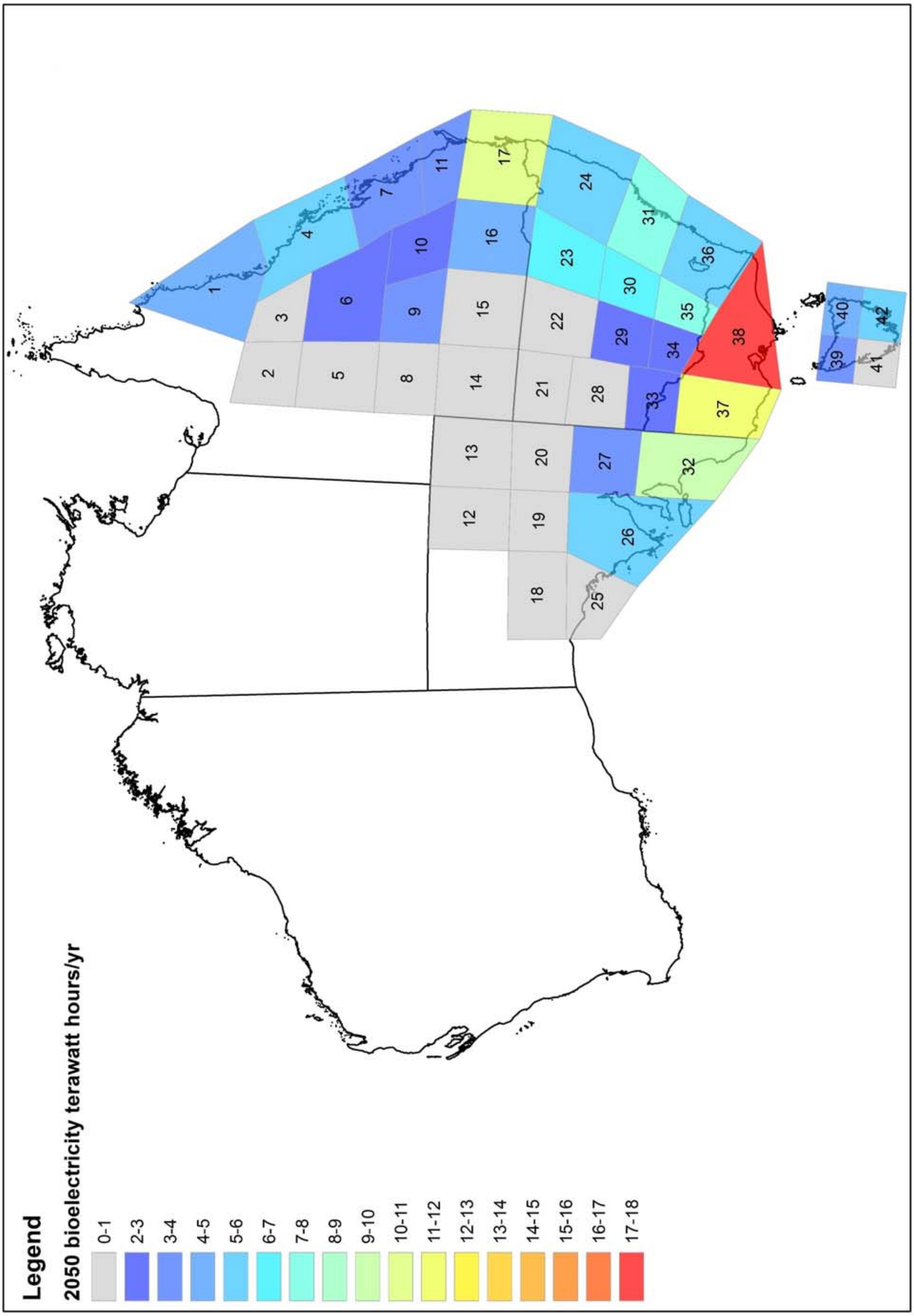

Figure 6. Spatial representation of the potential contribution of biomass to electricity generation (TWh/yr) in each of the 42 AEMO regions, period 2050

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Appendix A Population estimates

Population estimates (Table 10) on which the waste biomass per-capita calculations were based.

Table 10. Population estimates for 42 AEMO regions for 2010, 2030 and 2050.

AEMO REGION	HORIZON 2010	HORIZON 2030	HORIZON 2050
1	248904	363885	476452
2	4851	4839	6339
3	1363	1705	2234
4	352897	537298	696594
5	4872	4407	5775
6	28857	41424	54272
7	192003	277594	363688
8	749	773	1013
9	3484	3350	4390
10	5584	6827	8944
11	199857	313972	411350
12	249	219	242
13	150	132	147
14	544	534	699
15	7192	6248	8188
16	34981	37108	48237
17	3303487	5103120	6445687
18	187	180	200
19	5429	8536	9467
20	1021	876	972
21	710	630	717
22	9961	9534	10860
23	53025	44836	51076
24	497405	602203	686005
25	5930	6624	7347
26	91895	104227	115596
27	40715	42641	47289
28	21889	19691	22431
29	4965	4313	4913
30	97695	99100	112888
31	5256737	6735139	7666588
32	1434302	1773189	1966279
33	71137	85761	101310
34	56086	57763	66158
35	238480	287129	330516
36	833549	1045391	1195350
37	201189	217955	258766
38	4883363	6586962	7766553
39	99899	104740	106875
40	145073	161243	164528
41	2993	2573	2626
42	242788	288393	294271
Totals	**18686447**	**24993064**	**29523832**

Source: CSIRO calculations, based on ABS projections, per Methods section.

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