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Regional Resource Management Composite Curve

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A two-level approach to biomass supply chain synthesis based on a novel Regional Energy Clustering (REC) approach has been proposed. There are two main parts of the regional resources management. The first consists of forming clusters of zones for biomass management. The second part builds a Regional Resources Management Composite Curve (RRMCC). Generating a biomass transfer network between the various zones in a given region is an optimisation task determining the links and the biomass flows from the available energy surplus zones to the deficit zones. This is followed by grouping the zones into clusters using the combination of links and the overall energy imbalance as an objective function to be minimised. The information about the clusters is further plotted in the RRMCC with the cumulative land use on the y-axis and cumulative energy surplus-deficit as x-axis. This graphical representation shows the magnitude of the imbalance within each cluster and provides a tool for analysing the trade-off between land use and biomass generation, thus aiding regional planners in analysing the optimal land use on the one hand and the regional energy management surpluses and deficits on the other.

1. Introduction

The increasing of energy demand and CO_2 emissions from fossil fuels make switching to low-carbon energy technologies important. However, exploiting the RES potential may be constrained by the high production cost and high specific land use (area per unit of generated energy). Biomass is the RES that is most significantly limited by these constrains. The distributed nature of the biomass resources and its usually low energy density require supply chains with large transportation capacities. Biomass also requires huge land areas to collect and process the incoming solar radiation before the energy can be harvested.

The typical locations of biomass sourcing areas (farms, forests ect.) require extensive infrastructure. For biomass supply chains road transport is the usual mode for collection and transportation. As a result the heavy road transport may increase the carbon footprint (CFP) of the biomass energy generation. CFP as defined by POST (2006) is the total amount of CO_2 and other greenhouse gases emitted over the full life cycle of a process or product. The CFP has become an important environmental protection indicator as most industrialised countries have committed to reduce their CO_2 emissions

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by an average of 5.2% in the period 2008–2010 compared to the level in 1990 (Sayigh, 1999 and Perry et al, 2008).

With the growing demand for biomass energy crops, agriculture production and the space for development and the land use management form an environmental and societal trade-off. The land required to grow energy crops and refine them into marketable fuels could result in negative effects e.g. food price increases and deforestation (Koh and Ghazoul, 2008). This would in turn lead to the loss of biodiversity and create a conflict between the atmospheric carbon balance and natural ecosystems (Huston and Marland, 2003).

To tackle these problems, the Regional Energy Clustering (REC) algorithm has been introduced to analyse the energy surpluses and deficits from various zones (Lam et al. 2008), which can be matched to form energy supply chain clusters. A set of energy clusters is formed with minimum total CFP and reduced energy waste. The result of REC can be further illustrated in RRMCC. This graphical representation shows the magnitude of energy imbalance within each cluster and provides a tool for analysing the trade-off between land use and biomass generation, thus aiding regional planners in analysing the optimal land use on the one hand and the management of the energy surpluses and deficits on the other.

2. Regional Energy Clustering Algorithm

The concept of regional energy clustering (REC) has been presented by Lam et al (2008). An energy cluster is formed by combining smaller zones to secure sufficient energy balance within the cluster. A zone can be a province/county, an industrial park or an agricultural compound from the studied region. REC is used to manage the energy balancing among the zones. The energy surpluses and deficits from various zones can be matched and combined to form energy supply chain clusters. Forming the clusters aims at reducing energy waste and minimising the CFP during the biomass transportation and conversion.

The procedure for the REC Algorithm is:

1. Tabulate the energy source and demand data as illustrated in Table 1.

Table 1 Data for case studies

Z_i	Area (km^2)	Location (km, km)	Supply (PJ/y)	Demand (PJ/y)	Z_i	Area (km^2)	Location (km, km)	Supply (PJ/y)	Demand (PJ/y)
1	6.12	(0, 0)	0.05	2.90	6	5.57	(6.4, 5.5)	0.22	2.2
2	11.60	(4.1, 0.2)	2.35	0.12	7	10.63	(2.4, 6.8)	2.02	0.05
3	9.58	(4.4, 2.5)	0.78	0.41	8	7.83	(9.4, 5.5)	0.82	0.15
4	6.35	(5.3, 2.4)	0.70	0.23	9	4.12	(3.2, 6.6)	1.31	0.26
5	8.38	(7.9, 5.1)	1.07	0.21	10	3.15	(2.3, 7.3)	0.78	3.06

2. Obtain an optimised targeting result for the biomass transfer network/link using Linear Programming. The objective is to minimise the total CFP within the boundary of the given region. For biomass transfer from Zone i (source) to Zone j (sink) where varying $i = 1..N_{zones}$; $j = 1..N_{zones}$, $i \neq j$, the following objective function is defined:

Min $CFP = \sum_{ij} CFP_{i,j}$ (1)

$$CFP_{i,j} = FC_{i,j} \times Dist_{i,j} \times \frac{B_{i,j}}{C} \times CEF \quad (2)$$

where, $CFP_{i,j}$ is the Carbon Foot Print, $FC_{i,j}$ - Fuel Consumption, $Dist_{i,j}$ - 2-way distance , $B_{i,j}$ - Biomass load, C - the trucks capacity, and CEF is the Carbon Emission Factor for diesel trucks.

The following constrains are necessary:

a) The total amount of biomass transported out from Zone$_i$ to other zones can not exceed the available surplus AB_i:.

$$\sum_j B_{i,j} \le AB_i \quad \forall i., \quad B_{i,j}\|_{i=j} = 0 \quad (3)$$

b) The total bioenergy $TE_{i,j}$ delivered to Zone$_j$ cannot exceed the deficit in that zone:

$$\sum_i TE_{i,j} \le D_j \quad \forall j. \quad (4)$$

$$TE_{i,j} = HV_i \times B_{i,j} \quad (5)$$

HV_i is the heating value for the particular biomass from Zone$_i$ and D_j is the total demand in Zone$_j$.

c) The biomass load in the system must be non-negative

Clusters are formed based on the priority that the residual bioenergy imbalance within the newly formed cluster, R is minimised (preferably zero).

3. Regional Resource Management Composite Curve (RRMCC)

In Heat Integration, the Grand Composite Curve (GCC) is one of the most important tools used in Pinch Analysis for the selection of the appropriate utility levels (Linnhoff et al, 1982, 1994). The GCC was originally derived from the heat cascade via the Problem Table Algorithm. It is constructed from the enthalpy differences (x-axis) between the shifted composite curves at different temperatures (y- axis). GCC has been typically used for the heat exchanger network design. It gives a visualisation of the thermodynamically most favourable heat flows for Heat Integration problem. It shows the regions in where the process streams may recover heat internally. This can be represented by the pockets of the GCC.

The principle idea of GCC has been translated to the problem of regional resource management. RRMCC can be developed based on the result obtained from REC algorithm.

The procedure for RRMCC construction is:

1. Construct a cascade for biomass transfer between zones.
   i) Calculate the energy land use rate, L for each zone.

$$L_i = \frac{A_i}{S_i - D_i} \quad (8)$$

where, A_i is the Area for Zone$_i$, S_i and D_i is the bioenergy supply and demand from $Zone_i$.

ii) Order the clusters by descending imbalance. Start with the largest negative imbalance which is the zone with the largest energy deficit.
iii) Order the zones within the cluster by descending value of L_i.
iv) Cascade the surplus or deficit value of each zone from the bottom to the top.

2. If the region features a deficit in the total energy balance, sufficient energy has to be added (imported) to any intervals to make the total energy balance at least to be zero. The location of the energy imports depends on the need of the particular zones as well as the regional energy planning. If there is no import of energy into the region, then no energy is supplied to the intervals.
3. Plot the RRMCC with the cumulative area (km^2) as y-axis and the accumulated energy balance (PJ/y) on the x- axis. The coordinates for the points in RRMCC represent the accumulated area and the surplus/deficit value from cascade interval.

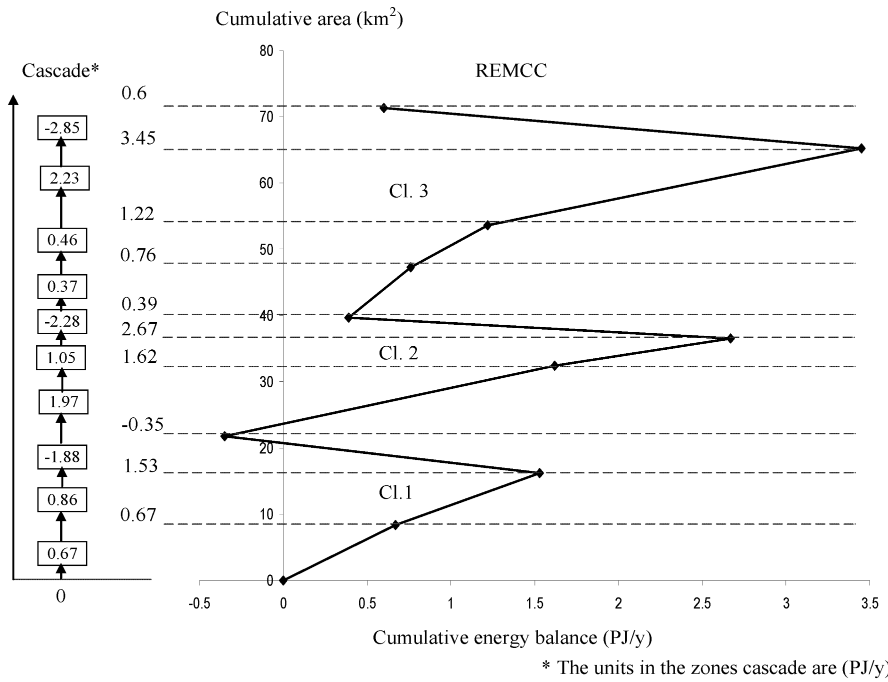

Fig. 1: Constructing of REMCC from cascade analysis

The result of the RRMCC based on the data in Table 1 is illustrated in Fig 1. As the case study has energy surplus overall, no energy import is needed. Therefore, no energy is added to the first interval. The first interval has a surplus of 0.67 PJ/y, which is cascaded to the next interval. The second interval has another surplus of 0.86 PJ/y, which leaves the regional energy cascaded from this interval to be 1.53 PJ/y. In the third interval, the process has a deficit of 1.88 PJ/y, which leaves -.0.35 PJ/y to be cascaded to the next interval and so on. The composite curve also shows that, the region is divided into 3 clusters. Fig 1 also indicates the size of each cluster and the total energy involved in the supply chain within the cluster.

RRMCC puts together the information about energy surpluses/deficits as well as land use, allowing to assess the trade-off between them directly. The quantity of the energy and the area for the zone are shown on the x-axis and the y-axis respectively. The zones with positive slope supply biomass to the demanding zones which are with the negative slope. This energy recovery is represented by the shaded pockets as shown in Fig. 2. Each left-hand turning point (could be also called a cluster pinch) indicates the start of a new cluster. The cluster will have surplus of biomass energy if the last point is plotted right side of the starting point otherwise the cluster will have energy deficit.

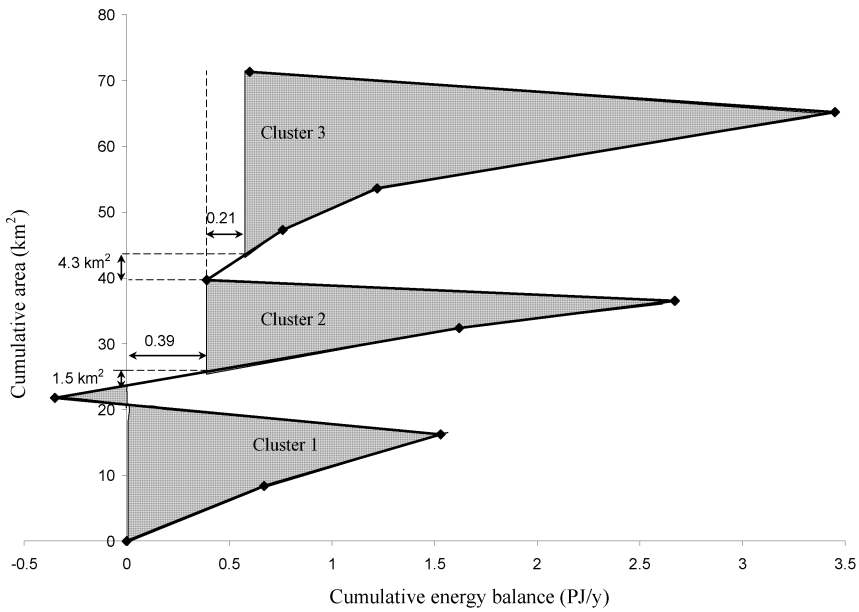

Fig. 2: RE-GCC for energy-land use trade-off management

The slope of RRMCC represents the *L* ($km^2/PJ\ y^{-1}$). This relationship gives the option to the planner to assess the priority: either to sell the surplus energy on the fuel market or use the land for other purposes. The decision can be based on a judgment of the market demand and the land use characteristics (Wang *et al*, 2003; Verburg *et al*, 2004). There are two areas in Fig. 2 which are not shaded. As a result the region still has a total biofuel surplus of 0.6 PJ/y of which is 0.39 come from Cluster 2 and 0.21 from Cluster 3. This total balance should be assorted with the balance from cascade analysis. The RRMCC also shows that there are 1.5 km^2 and 4.3 km^2 of vacant land in Cluster 2 and 3 respectively which are available to be used for other purposes, such as food plantation or other commercial products generation.

Conclusions

A new approach for regional resource management has been developed and demonstrated. It is based on the regional energy cascade. Cascade is a tool to assess the energy target within regional supply chains. It provides the clear result for energy flow evaluation, how much energy needs to be imported and the locations of the demands. The energy planning and management is extended to the evaluation of the trade-off between biomass generation and land use. This is made possible by using the RRMCC, which graphically represents the relationship between the land use and the generation and consumption of energy. The case study shows that, the region is getting 0.6 PJ/y of surplus energy to be exported or 5.8 km^2 of land that available for other purposes. For future work, the application of RRMCC will be extended to additional applications such as (i) managing the energy and land use by changing the slope of RRMCC (ii) determine the locations of the import and export centres for the regional energy supply chain.

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