A weighted goal programming approach for planning regional development: a case study of Queensland, Australia

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Abstract

In Queensland, Australia, an Economic Impact Assessment (EcIA) is an important part of the approval process for major projects. Majority of EcIAs are conducted under a presumption that the projects are bringing positive values to the economy only on the basis of additional royalties, output, employment and income. EcIA does not usually provide detailed understanding of the trade-offs associated with competing development goals. While Queensland economic development relies on the future growth of coal mining industries, the benefits to regional communities might be hindered by many different environmental impacts related to coal mining activities including the impacts of ecosystem service. However, a decision situation for the approval process for major projects can described by multiple and conflicting goals including environmental impacts, such as land use, employment opportunity, and income. Goal programming is also known as multi-objective optimisation, which is classified as one of the commonly used in multi-criteria decision analysis. In this paper, we propose a goal-programming model to handle practical example with different trade-off scenarios in coal mining industries and to evaluate ecosystem service. In the proposed model, we introduced the deviation variables and weight into the conflicting objectives from policy makers' perspective for evaluation purpose. Our proposed model can aid decision makers to achieve effective strategic planning.

Keywords:
Regional planning; Economic development; Energy policy; Environmental Impact Assessment; Sustainability; Ecosystem Services; Geographic Information Systems

JEL classification:
Q01; Q24; Q32; Q51; Q56; Q57

1. Introduction

Economic Impact Assessment (EcIA) plays an important role in a project's approval. However, the main effects of the projects are typically limited to employment and income. While environmental and social impacts are evaluated using separate assessments, they are rarely taken into consideration in the EcIA. Growth in coal industry corresponds to the increase in land which is diverted from other potential uses such as agriculture to the coal mining. Queensland has about 40% of total Australian black coal reserve (Zheng et al., 2007). Central Queensland produces about 85% of coal in Queensland. In the Central Queensland, the coal mining industry creates employment, income, and royalties. However, activities associated with the coal mining may have significant impact on the environment and communities.

In particular, the environment impacts consist of the amount of the land use and degradation, water resource damage, increased solid wastes, potentially gas piping leakage, excessive noise pollution, generated excessive acid wastes, and significant influence of habitat and biodiversity balance (Ranjan, 2019). In addition, mining activities influence many different scenic values and cultural heritage of mined sites in the Central Queensland through removal of sacred forests/groves (Zheng et al., 2007).

The regional development and justification for projects approvals can be classified into the measurable economic, social and environmental aspects as follows (Lechner et al., 2016, Ogbonna et al., 2015).

i) Economic goals including
   a. Minimisation of investment
   b. Maximisation of net present value
   c. Maximisation of profit
   d. Maximisation of production
   e. Minimisation of unemployment
ii) Social goals including
   a. Maximisation of social benefits
   b. Maximisation of safety
   c. Maximisation of employment opportunity
   d. Maximisation of income
iii) Environmental goals including
   a. Minimisation GHG emissions
   b. Minimisation environmental degradation
   c. Maximisation of land use

To maintain all these strategic goals for policy makers, it may be challenging and sometime, difficult to achieve. In this paper, we proposed and developed a conceptual idea for analysing and evaluating the scenarios using goal programming (GP) model related to regional development. We used three goals such as employment, income and land use in order to simplify the model for the proof of concept purposes. The model can be extended to include other important aspects of regional development. In the following sections, we discuss the GP model, related applications, a simple hypothetical case and suggest future research directions. Finally, the conclusions are presented and summarised.

2 A weighted GP for case study

The study area (that is proposed to be used for future analysis) covers three natural resource management (NRM) regions – Burdekin, Mackay Whitsunday and Fitzroy– along the Great Barrier Reef in Central Queensland, North-East Australia. Figure 1 shows current land use patterns (Figure 1.A.) and stresses the growing area covered with coal mines (Queensland Government, 2019). Figure 1.B and 1.C present two likely stages of evolution of the surface covered with coal mines in the future, if all mining leases currently granted until 2047 would be fully exploited. The increasing dominance of coal mines over other types of land use in this region seems to be approved without due consideration of potential significant impacts on local communities and the environment.

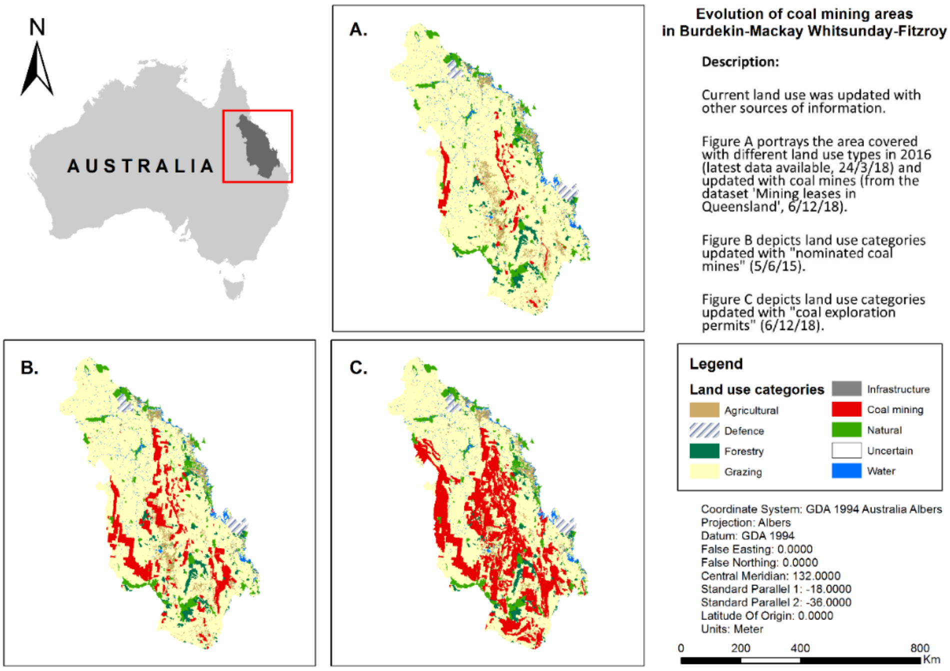

Figure 1. Projected coal mining areas according to coal exploration permits, Central Queensland (current situation to year 2047)

To date, coal mining has been the preferred option in this area due to the perceived large benefits generated by this industry such as employment and income. Compared with agriculture, grazing or even nature conservation, coal mining is deemed far more lucrative. Unfortunately, coal mining also generates a whole range of environmental impacts whose cost is traditionally not accounted for, leading to biased and myopic decision-making. For instance, coal mining is responsible for land degradation, air and water pollution, and contributes to the erosion of biodiversity in exploited areas. In addition, the opportunity cost of using land for coal mining rather than for less or non-destructive options is neither considered in the economic impact assessment. Ecosystem services, i.e. the goods and services derived from nature itself (e.g. freshwater, timber, pollination), result in substantial direct and often indirect economic benefits that should justify the crucial importance of conserving nature in the long run. Alternatively, grazing is a low-impact form of land use (compared to mining) that remains essential to support local economies in regional Queensland.

We argue that the proper consideration of different development goals together with a long-term perspective might change the project approvals more towards agricultural land use.

3 GP Model and related applications

Choosing a project that assists in achieving several goals can be a daunting task for policy makers. The linear programming approach is no longer appropriate when a decision maker is challenged with multiple objectives. In addition, each goal might have different priorities. For example, the reduction of unemployment might be seen as a number one priority, while the land use might be seen as of a lesser importance. The GP is more appropriate tool to examine and evaluate multiple objectives simultaneously. GP is the extension of linear programming, which is often used for evaluation multiple objective optimisation problems (Alidrisi and Mohamed, 2012, Broz et al., 2019). A decision maker can attempt to minimise the deviation of goals and consider the trade-off scenario based on the existing resource availability and limitations associated with the issues (Shekdar and Mistry, 2001, Soorajkrishna et al., 2018). GP has also been successfully applied to solve many different types of applications including project selection, coal mining policy, and environmental impact associated with coal mining (Lechner et al., 2016, Mukherjee and Bera, 1995, Ogbonna et al., 2015, Ranjan, 2019).

Some of the most commonly used GP approaches are Chebyshev goal programming (CGP), weighted goal programming, extended goal programming and meta-goal programming. Each of these approaches does have its strengths and weaknesses. CGP can offer better outcome by considering the balance between achievements and results may be unsatisfactorily aggregated (Alidrisi and Mohamed, 2012, Broz et al., 2019, Jong et al., 2018, Lu et al., 2008).

Dowlatshahi (2001) proposed use of goal programming to analyse different stages of product lifecycle analysis by aligning the organisational strategic intermediate and tactical goals. Sun et al. (2017) also developed an interval programming optimisation model to focus on the air quality and environmental aspects. In value chain planning, Schniederjans et al. (2017) proposed the GP to be incorporated with elements of critical path method and concurrent engineering to evaluate different value analysis projects. A variety of hybrid model has also been used widely to consider a time-cost trade-off in scheduling. Mansoori et al. (2009) developed a lexicographic goal programming to evaluate the environmental conservation program in farm activities. These performance evaluation and analyses for farming activities were conducted based on the trade-off scenario of economic, environmental and compromise aspects.

For the energy planning and selection, Huang et al. (2017) focused on the community energy system design and introduced the GP to evaluate multiple objective optimisation. In the GP model, the decision variables and weight were used for constrain items and achievement function. Then, the total fossil energy consumption is also part of goal function. A case application was conducted in Tianjin, China to show the effectiveness and efficiency of the proposed model. Broz et al. (2019) also examine practical application using GP for the decision support in the daily production planning of sawmill.

In a review of current literature for project selection, coal mining policy, and environmental impact, there appears less practical case studies in the way of modelling multiple decision-making scenarios based on regional development goals including the growth in coal mining, agricultural, transportation and trades and others industries (Alidrisi and Mohamed, 2012, Baykasoglu, 2001, Ben Ruben et al., 2017, Lechner et al., 2016). Numerous case applications of GP or hybrid GP mainly focus on the effectiveness of project selection in energy consumption plans, chemical and hazardous pollutants and waste generation from various industries. The practical implications and justifications for the regional economic development in relation to the coal mining, agricultural and transportation and trades industries are still at the budding stage. The regional development may have impacts on the community employment opportunities, the control of land usage by industries, and the increase of total household incomes. The Economic impact assessment can benefit from using the GP to assess the projects on the basis of achieving the strategic regional development goals.

4. Model formulation using goal programming

In this type of environmental impact assessments, many different inputs are manipulated through data interpretation and analysis to produce a single output. This output must be consistently met the specifications for a number of target characteristic. The range of those values must be within some specifications. Each different input must also define and the limits for environmental impacts are known. The impact assessment including environmental, social and economic can be used to determine input levels, and decision variables land the specifications on output characteristics subject to their constraints. The results of the GP help to find either an optimal solution or estimate the best compromise solution (Baykasoglu, 2001, Broz et al., 2019).

The model formulation is derived by minimising the sum of the anticipated goal deviation variables. This model is subject to the anticipated goal constraints due to the consideration taken to the priority structure. The general model for GP was first proposed by Charnes and Cooper (2016), which is known as classical formulation is described as:

$$Minimise\ Z = \sum_{i=1}^{p} d_i^- + d_i^+ \quad (1)$$

Subject to

$$\sum_{j=1}^{n} A_{ij}X_j + d_i^- - d_i^+ = b_i \quad (2)$$

$$X \in \omega \quad (3)$$

$$d_i^-, d_i^+ \geq 0 \qquad i = 1,2\ldots m \quad (4)$$

where ω is the feasible set, X_j are the input variable representing the number of elements to be considered for the case, the coefficient A_{ij} states the contribution of the j^{th} variable to the achievement of the i^{th} criterion $F_i(X_1, X_{2,\ldots,}X_n) = \sum_{j=1}^{n} A_{ij}X_j$, In goal programming, d_i^+ and d_i^- are represented as deviation variables. To segregate those different weighted inputs, the weighting ratio of W_{ij}^- and W_{ij}^- are integrated with the model. It can then be expressed as the weights associated with positive and negative deviations of each goal. The purpose using weighting ration and deviation variables to assign different goals allows for the possibility of not meeting the target value and trade-off decision can then be made.

$$Minimise\ Z = \sum_{j=0}^{J}\sum_{i=1}^{m} P_j\left(W_{ij}^- d_i^- + W_{ij}^+ d_i^+\right) \quad (5)$$

Subject to:

$$\sum_{j=1}^{n} A_{ij}X_j + d_i^- - d_i^+ = b_i \quad (6)$$

$$X \in \omega \quad (7)$$

$$d_i^-, d_i^+ \geq 0 \qquad i = 1,2\ldots m \quad (8)$$

In this paper, we formulate the trade-off scenario model that simultaneously consider the following aspects criteria, such as (i) employment, (ii) household income, and (iii) mining land value for hypothetical case testing.

5. A simplified GP for hypothetical case

To conduct a simple test to understand the practical implications of the GP Model, we analysed the trade-off scenario based on the employment, land use and household income aspects for few different industrial sectors (i.e. agricultural, mining, and transportation). The hypothetical case was tested under the following pre-defined conditions, where the ratio of the number of employments, land use proportion and the household income in region “A” and “B” are estimated. Figure 1 and 2 show the obtained results from the GP model using Excel Spreadsheet for region “A” and region “B”. The anticipated goals for regional development (i.e. agricultural, mining and transportation sectors) were set as 0.90 (total number of employment level for region “A”), 0.10 (total land use proportion for region “A”) and 0.90 (total household income level for region “A”). The decision variables of X1 (agricultural sector), X2 (mining sector) and X3 (transportation sector) represent the approximation of the incremental development rate to maintain the satisfactory level of the anticipated goals in relation to the national regional development benchmarks. Based on the hypothetical settings, we obtained the incremental development rate of these sectors respectively. It has scored of 6.923 (agricultural), 0.692 (mining) and zero (transportation and trade) for region “A”. Therefore, it can be said that we can achieve the anticipated goal settings if we are able to maintain the incremental development rate for the agricultural and mining sectors. However, we need to compromise the land use proportion for these sectors in the region “A” because the land use proportional ratio is exceeded with the anticipated goal of 0.1 ratio (total land use proportion for region “A”), which is above the amount of 1.4231.

The anticipated goals for agricultural, mining and transportation trade sectors of these important aspects remain unchanged for region “B”. As a result, we obtained the incremental development rate of these sectors respectively. It has scored the ratio of zero (agricultural), 1.500 (mining) and zero (transportation and trade). Therefore, it can be said that we need to maintain the incremental development ratio for mining industry at the level of 1.500.

Regional A:- Goal Programming (Weighted)

	Agri X1	Mining X2	Transp X3	Goals: Level Achieved		Goals: Goal	Deviations: Amount Over	Deviations: Amount Under	Constraints: Balance (Level - Over + Under)		Constraints: Goal
Employement	0.06	0.70	0.08	0.9000	>=	0.90	0	0	0.9	=	0.9
Land Use	0.20	0.2	0.1	1.5231	<=	0.1	1.4231	0	0.1	=	0.1
Househould Inc.	0.05	0.80	0.10	0.9	>=	0.90	0	0	0.9	=	0.9

	X1	X2	X3
Variables	6.923077	0.692308	0

Penalty Weights	Over Goal	Under Goal
Employment		0.8
Land Use		0.8
H.Inc	0.8	

Weighted Sum of Deviations
0.00000

Range Name	**Cells**
AmountOver	J6:J8
AmountUnder	K6:K8
Balance	M6:M8
Deviations	J6:K8
Goal	H6:H8
LevelAchieved	F6:F8
PenaltyWeights	J13:K
Decision Variables	C12:E
WeightedSumOfDeviation:	M13

Figure 1. Hypothetical Case for Region A

Regional B:- Goal Programming (Weighted)

	Agri X1	Mining X2	Transp X3	Goals: Level Achieved		Goals: Goal	Deviations: Amount Over	Deviations: Amount Under	Constraints: Balance (Level - Over + Under)		Constraints: Goal
Employement	0.04	0.60	0.06	0.900	>=	0.90	0	0	0.9	=	0.9
Land Use	0.80	0.03	0.015	0.045	<=	0.1	0	0.055	0.1	=	0.1
Househould Inc.	0.03	0.70	0.06	1.050	>=	0.90	0.1500	0	0.9	=	0.9

	X1	X2	X3
Variables	0	1.500	0

Penalty Weights	Over Goal	Under Goal
Employment		0.8
Land Use	0.8	
H.Inc		0.8

Weighted Sum of Deviations
0

Range Name	**Cells**
AmountOver	J6:J8
AmountUnder	K6:K8
Balance	M6:M8
Deviations	J6:K8
Goal	H6:H8
LevelAchieved	F6:F8
PenaltyWeights	J13:K15
Variable	C12:E12
WeightedSumOfDeviation:	M13

Figure 2. Hypothetical Case for Region B

In these case applications, there are also few implications for both obtained results of region "A" and "B". It means that the incremental development ratio for mining industry must be maintained at 0.692 in the region "A" and at 1.500 in the region "B". In other words, the mining developers might have more opportunity to expand their future business in the region "B" not in the region "A". The percentage difference is about 53.7%. However, there is no opportunity for agricultural and transportation and trade sectors in the region "B" and there would have opportunity for agriculture sector for their business expansion in the region "A". In addition to that, there is no future development opportunity in relation to the transportation sector for both regions.

6. Summary

In this paper, we proposed a GP model to handle practical example with different trade-off scenarios in different industry. We also introduced the deviation variables and weight into the conflicting objectives from the policy makers' perspective for evaluation purpose. Our proposed model can aid decision makers to achieve effective strategic planning while assessing different development options and projects approvals. Based on the hypothetical case, the results obtained showed that incremental development ratio for mining sector must be maintained at 0.692 in the region "A" and at 1.500 in the region "B". In other words, the mining developers might have more opportunity to expand their future business in the region "B" but not in the region "A". The percentage difference is about 53.7%. Although these are the hypothetical case scenario, it can provide us the practical insights and implications to determine which sector would have better future business development opportunity in any region. In addition to that, the extended work for trade-off case scenario will be conducted based on coal mining as discussed in Section 2. As we know that the coal mining sector has generated large benefits if compared with agriculture, grazing but natural conservation is also important.

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