Optimizing the Winery Operational Scheduling under the Requirement of CO$_2$ Emission Reduction: A Case Study of Hualien Tourism Winery

Shiang Chen and Jung-Hua Wu
Department of Resources Engineering, National Cheng Kung University, Tainan City, Taiwan
Email: n48001050@mail.ncku.edu.tw, hwaa@mail.ncku.edu.tw

Abstract—In this study we use the methods of linear programming model and carbon tax to explore the optimal production of winemaking industry. During the winemaking processes, we must use electricity, fuel oil, and steam, as major energy. The final productions are wine product, wastewater, lees, and CO$_2$, etc. Different process modes will produce different energy consumption, thus providing a possibility in CO$_2$ reduction. In the text first we establish the linear programming model, and then under the goal of profit maximization, we explore the carbon tax and the interrelationship caused by changes in energy consumption and the CO$_2$ reduction. The results show that under different carbon tax levels and operational changes in production schedules that will change the usage of energy and thus reduce the total CO$_2$ emissions [1]. Carbon tax can trigger the effect of CO$_2$ reduction. When carbon reduction cost is equal to the taxable cost, the tax effect of CO$_2$ reduction will result. It shows that profit and loss balance point is the best carbon tax price [2], finally we also analyze the CO$_2$ inventory policy of winery during the period 2006-2016, the main sources of greenhouse gas emissions were fuel oil, and wastewater.

Index Terms—wine-making process, linear programming, carbon tax

I. INTRODUCTION

In Taiwan we are currently facing serious air pollution problems. China ranks first in the world for carbon dioxide emissions and has announced the “National Carbon Emission Trading Market Construction Scheme.” Compared to the international market, Taiwan’s emissions trading market is small. It may not be able to produce effective carbon prices or be a driving incentive for reduction. In other words, the effect of emissions trading may not be better than the collection of carbon tax [3]. Therefore, in this study we have used linear programming, carbon tax, and inventory of energy-saving & carbon emissions to explore optimal production in the winemaking industry.

In the first part of this study, the linear programming model of the winemaking industry is established. Second, assuming the goal of minimizing costs and maximizing profits, we discuss the influence of changes to energy consumption and the decrease of CO$_2$ due to the levying of carbon taxation on the cost [4]. By using cluster analysis, we explore the energy consumption during the winemaking process and analyze the implementation of the greenhouse gas inventory measures then we analyze and compare the sources of greenhouse gas emissions at the winery during 2006-2016 [5].

A. Energy Consumption and Greenhouse Gas Emissions in the Wine Industry

The beginning of Taiwan’s winemaking industry was in 1947. Tobacco and alcohol bureau was established then changed the name into Taiwan Tobacco & Liquor Corporation - TTL in 2002 July. Rice wine is the most traditional, the largest and the most representative of wine products in Taiwan. In Winery there are five categories and 11 kinds of alcoholic products, in this study we choose 7 kinds of rice wine products as research objects, the different of product with different process and CO$_2$ emission, the process of winemaking is as follows:

![Figure 1. Rice wine-making process](image-url)

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consumption of energy, and the proportion will change with the adjustment of industrial structure. Fig. 2 was the historical statistics of domestic energy supply and demand situation. According to statistics, in 2016 the supply of imported crude oil and petroleum products had been accounting for 48.9% of total supply. The wine-making industry must use heavy oil as a fuel for energy use and emissions \( \text{CO}_2 \). The environmental problems caused by the GHS are deteriorating now. How to improve our economic development and protect the environment becomes a common challenge.

C. Analysis of Greenhouse gas Emissions 2006-2016 in Winery

Analysis of the types of greenhouse gas emissions from 2006 to 2016, as shown in Fig. 3, the source of \( \text{CO}_2 \) emissions were fixed fuel oil as the main source, followed by wastewater, process emissions, electricity and outsourcing.

In Taiwan, our greenhouse gas reduction targets are to achieve greenhouse gas emissions reductions for 2025 carbon dioxide emissions and encourage energy-intensive industries to use the best energy efficient technology (BAT) to effectively manage energy and improve efficiently, especially in industries that must seek the most efficiency use of energy, that is, the minimum \( \text{CO}_2 \) emissions operation, to pursuit profit maximization. Through the data analysis, the winery from 2006 to 2016, the source of greenhouse gas emissions, with fixed fuel oil as the main source, the results of greenhouse gas inventory shows that \( \text{CO}_2 \) emission has been improving year by year.

II. LINEAR PROGRAMMING MODEL OF WINE INDUSTRY

By the model of the linear programming, first we set carbon tax prices, by \( \text{CO}_2 \) taxation mechanism to analyze changes in the production scheduling process and energy usage, then under the goal of maximizing profit, to explore the interaction between changes in production scheduling and \( \text{CO}_2 \) emissions reductions [6].

A. The Goal of the Linear Programming Model for Wine Industry

The goal of the linear planning model of wine Industry is the combination of output interest, input cost and carbon cost, expression in monetary terms; the energy goal is to minimize energy input, in terms of quantity or currency; the environmental goal is to minimize \( \text{CO}_2 \) emissions by quantity. Therefore, there are three targets of the linear planning model, they are economy, energy and environmental protection. Since the purpose is to produce in the production process of obtaining the maximum profit, however, profit is the value of the product portfolio produced in the production process and the cost invested in the manufacturing process, therefore in this text; we must consider minimizing \( \text{CO}_2 \) emissions the environmental objectives. The following shows the concept of wine industry; its targets are as follows:

1. Economic target: Optimize the allocation of resources, the pursuit of the maximization of production value.

2. Energy Target: Fixed capital investment, the pursuit of the minimum energy supply

3. Environmental target: The pursuits of optimal profit conditions, \( \text{CO}_2 \) emissions are minimized. The mathematical formula can be measured in monetary units.

B. Establishment of Linear Programming Model for Wine Industry

Linear programming can be mathematically expressed as follows:

Maximize: \[ \sum_{i=1}^{M} P_i a_i - \sum_{i=1}^{M} C_i a_i - \sum_{i=1}^{M} E_i a_i - P_e \sum_{i=1}^{N} Q_i a_i \]

Subject to:

\[ \sum_{i=1}^{M} a_i \leq \text{CAP}_i, \quad i = 1, \ldots, M \]

\[ a_i \leq \text{R}_i, \quad i = 1, \ldots, M \]

\[ \sum_{i=1}^{N} Q_i a_i \leq \text{CO}_2 \]

Where \( M \), \( N \), and \( P \) products.

\( a_i \) means the quantity of product \( i \) produced in one month.

\( P_i \) means the price of product \( i \).

\( C_i \) means the cost of product \( i \).

\( E_i \) means the energy consumption (water, fuel, and electricity) of product \( i \).

\( P_e \) means the carbon tax.

\( Q_i \) means the \( \text{CO}_2 \) emission of product \( i \).

\( \text{CAP}_i \) means total quantity limitation.

\( \text{R}_i \) means the limitation quantity of product \( i \).
CO₂ emission = the limitation of CO₂ emission.

SEC i is the measure of the proportion of energy consumption in the production facility, which can be defined as a physical measure of the proportion of energy consumption in production activities to produce inputs or outputs, they are expressed in SEC as follows:

\[ SEC_i = \frac{E_i}{m_i} \]

C. Unit Energy Consumption Setting and Cluster Analysis

Based on the unit energy consumption characteristics of rice wine manufacturing process, in this study, we use the method of cluster analysis. The purpose of this is to attribute the energy consumption of the process with different characteristics to analyze the change of production capacity of low-energy cluster process and the relation of CO₂ reduction, we use specific energy consumption (SEC), which can be defined as a physical measure of the proportion of energy consumption in production activities to produce inputs or outputs, they are expressed in SEC as follows:

\[ SEC_i = \frac{E_i}{m_i} \]

Using the above calculation method of unit energy consumption (SEC), we can get the numerical value of the energy consumption of each process unit, and divide the energy consumption into unit heat energy produced by fuel, steam and electricity. The data source of unit energy consumption analysis is based on the indicators of energy supplies declared by the wine producers in the annual. As the operating process changes; the usage of energy is also changing. Under different carbon tax, the total energy consumption is also different, when un-taxed, there is the highest amount of emissions, after carbon tax is levied, in order to reduce the emission of CO₂, and the production structure will be operated in the direction of low energy consumption to reduce the total energy consumption so as to reduce the emission of CO₂.

### TABLE I. UNIT ENERGY INPUT AND CLUSTER CHARACTERISTICS UNIT: /MONTH

<table>
<thead>
<tr>
<th>Name of product</th>
<th>CO₂ emission</th>
<th>Fuel oil Ton/month</th>
<th>Electricity Kwh/month</th>
<th>Water (steam) Ton/month</th>
<th>Cluster characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red label rice cooking wine (0.6L)</td>
<td>129.09</td>
<td>3457.97</td>
<td>23.50</td>
<td>3432.66</td>
<td>high</td>
</tr>
<tr>
<td>Red label pure rice cooking wine (0.6L)</td>
<td>1.40</td>
<td>37.50</td>
<td>0.25</td>
<td>36.77</td>
<td>low</td>
</tr>
<tr>
<td>Super red label rice wine (0.3L)</td>
<td>142.44</td>
<td>3818.65</td>
<td>25.94</td>
<td>3,788.18</td>
<td>high</td>
</tr>
<tr>
<td>Super red label pure rice wine (0.3L)</td>
<td>143.01</td>
<td>3830.92</td>
<td>26.02</td>
<td>3800.44</td>
<td>high</td>
</tr>
<tr>
<td>Super red label pure rice wine (0.6L)</td>
<td>23.43</td>
<td>672.85</td>
<td>4.28</td>
<td>625.234</td>
<td>medium</td>
</tr>
<tr>
<td>Red label rice wine water (0.6L)</td>
<td>18.55</td>
<td>497.13</td>
<td>3.35</td>
<td>490.38</td>
<td>medium</td>
</tr>
<tr>
<td>Gift box (wine)</td>
<td>2.73</td>
<td>73.28</td>
<td>0.50</td>
<td>73.55</td>
<td>low</td>
</tr>
</tbody>
</table>

III. FUEL CONSUMPTION OF RICE WINEMAKING

Using the above calculation method of unit energy consumption (SEC), we can get the numerical value of the energy consumption of each process, and divide the energy consumption into unit heat energy produced by fuel, steam and unit energy used by electricity [7]. The data source of unit energy consumption analysis is based on the indicators of energy supplies declared by the wine producers in the annual report of ITRI manufacturing energy users, including energy consumption per unit of heat (steam and fuel) and unit electricity energy.

A. Rice Wine Revenue and Costs in 2017

After levying a carbon tax, due to the increase in the carbon tax cost, to reduce the CO₂ emission cost, the industry will reduce the fixed costs and the operating costs through the reduction of fuel consumption and the adjustment of operating costs. The total cost will increase due to the taxable cost of CO₂ emissions; however, as the carbon tax level increases, the ratio of fixed costs and operating costs, total costs will decrease slightly. The practice of energy conservation and carbon reduction can be achieved through the levy of carbon tax. The method of reducing CO₂ emissions can be achieved by raising the selling price of the product and thus reducing the demand for rice wine, or by reducing the profit of winery directly suppressing the production of the wine industry. However, the price of rice wine must be considered consumer’s acceptance, on the other hand, to raise the cost of wine industry operators, we must consider the impact of high costs on the industry's competitiveness in the free market. In other words, raising the carbon tax level, although conducive to CO₂ emission reductions, however, once the cost has been raised to a certain level, the absence of related measures will significantly increase the overall production cost of the industry will be unfavorable to the competitiveness of the wine industry.

### TABLE II. RICE WINE TOTAL REVENUE AND COSTS 2017

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Total revenue</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Amount USD/year</td>
<td>Total revenue %</td>
</tr>
</tbody>
</table>

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B. Empirical Results and Analysis

The data analysis is to illustrate the source of research data, MATLAB simulation software and the CVX module are used to solve the problems of linear programming model [8], this study simulated changes in production based on whether the carbon taxation was levied or not and the carbon taxation levied. Under the basic situation of maximizing the target of economic benefits and minimizing the target of energy consumption, the research model obtains the production benefits, total benefits and minimizing the target of energy consumption, basic situation of maximizing the target of economic benefits and environmental targets in the objective function are brought into the research model [9]. The result of solving each carbon tax level and basic situation as shown in Table III under different carbon taxation levels. In addition, the setting of carbon taxation , we adopt the observation index of the literature, taking into consideration the current actual carbon taxation transaction prices and setting them at six levels of 10, 30, 60, 90, 120, 150, USD / metric ton CO₂. It is used to construct the linear programming model of wine industry, as a taxation and different carbon taxation standards under the empirical simulation basis and analyzes the impact of changes in energy consumption and CO₂ reduction caused by the levy of the carbon taxation. The results under different carbon tax levels.

<table>
<thead>
<tr>
<th>CO₂ price,USD /MT</th>
<th>0</th>
<th>10</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6L TTL red label rice cooking wine</td>
<td>129.09</td>
<td>129.08</td>
<td>124.20</td>
<td>116.86</td>
<td>123.73</td>
<td>106.45</td>
<td>114.67</td>
</tr>
<tr>
<td>0.3L TTL red label pure rice wine</td>
<td>144.40</td>
<td>140.95</td>
<td>136.94</td>
<td>146.69</td>
<td>138.09</td>
<td>123.35</td>
<td>136.85</td>
</tr>
<tr>
<td>0.6L TTL red label pure rice wine</td>
<td>143.01</td>
<td>142.49</td>
<td>140.64</td>
<td>139.97</td>
<td>140.86</td>
<td>159.08</td>
<td>134.67</td>
</tr>
<tr>
<td>0.6L TTL red label pure rice wine</td>
<td>23.34</td>
<td>23.19</td>
<td>22.53</td>
<td>24.14</td>
<td>22.72</td>
<td>20.29</td>
<td>22.51</td>
</tr>
<tr>
<td>18.588</td>
<td>18.70</td>
<td>18.34</td>
<td>17.20</td>
<td>17.24</td>
<td>18.82</td>
<td>16.29</td>
<td></td>
</tr>
<tr>
<td>2.73</td>
<td>2.72</td>
<td>2.68</td>
<td>2.67</td>
<td>2.69</td>
<td>2.86</td>
<td>2.57</td>
<td></td>
</tr>
</tbody>
</table>

C. Analysis of the Tax Effect

In terms of cost-effectiveness, when CO₂ reduces emissions costs equal to the carbon tax costs, we get the best carbon tax. At this point, the cost of investing in CO₂ to reduce emissions will equal the amount of CO₂ levied tax cost, in other words, the relative CO₂ emission at this time is the emission at the optimal production level, and when reducing CO₂ emissions costs lower than the cost of tax, the wine industry will try its best to reduce CO₂ emissions, however, when the cost of reducing emissions is higher than the cost of tax, wine industry will adopt a strategy of preferring to pay carbon tax to save costs, that is to say, after the CO₂ tax, whether the wine industry will pay carbon tax...
substantially reduce its carbon emissions it determine whether the taxable cost of CO\(_2\) has already exceeded the CO\(_2\) emission reduction costs. When CO\(_2\)'s taxable costs are lower, it is less likely to commit itself to carbon reduction because carbon tax is beneficial to the industry [10].

<table>
<thead>
<tr>
<th>CO(_2) price ,USD /MT</th>
<th>10</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT/month</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>0.10</td>
<td>2.63</td>
<td>4.15</td>
<td>4.31</td>
<td>6.70</td>
<td>8.59</td>
</tr>
<tr>
<td>Profit and loss costs,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USD/MT-CO(_2)</td>
<td>9.36</td>
<td>26.26</td>
<td>56.67</td>
<td>83.57</td>
<td>110.81</td>
<td>130.20</td>
</tr>
<tr>
<td>CO(_2) tax effect</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USD/MT-CO(_2)</td>
<td>0.63</td>
<td>3.734</td>
<td>3.32</td>
<td>6.42</td>
<td>9.18</td>
<td>19.80</td>
</tr>
<tr>
<td>The ratio of carbon (%)</td>
<td>6.38</td>
<td>12.44</td>
<td>5.54</td>
<td>7.13</td>
<td>7.65</td>
<td>13.20</td>
</tr>
</tbody>
</table>

Changing in production may reduce energy consumption costs because of a reduction in energy usage; however, due to the newly increased high cost of tax and the decrease of output value and the increase of the taxable cost due to the decrease of output, the production benefit after tax has been reduced substantially.

IV. CONCLUSION

In this study, we make use of the linear programming model to explore a complicated winemaking process we compare changes in CO\(_2\) emissions when the carbon tax is not levied and the carbon tax is levied. The research goals are to minimize the demand for energy usage, to minimize CO\(_2\) emission requirements and pursuit of maximizing production value. The process of simulation is first to simulate the situation of carbon tax which has not been levied as a basic situation, and then to calculate the total emission of CO\(_2\) under the basic situation as the discharge constrain, finally, under the different levying standards of carbon tax, to simulate a variety of circumstances.

The results show that:
1. The winemaking industry under different carbon tax levels, the producer will undergo to change production schedules, they have changed the structure of their energy usage towards lower-carbon production that will reduce the usage of energy and thus reduce the total CO\(_2\) emissions.
2. As a result of carbon tax levies, wine industries are also under pressure to reduce their total costs, the higher the levy of carbon tax, the greater the effect of carbon reduction. However, when the carbon tax is too high, the high cost of tax barriers will occur and the output of the study with the final demand of each product, the carbon reduction effect is limited.
3. In terms of cost, the levy of carbon tax can trigger the effect of CO\(_2\) reduction. When wine industry’s carbon reduction cost is equal to the taxable cost, the carbon tax effect of CO\(_2\) reduction will result. The profit and loss balance point is the best carbon tax level. If the carbon tax level is greater than the best tax rate at the P & L balance, there is an incentive to force the industry to make a mandatory reduction.

After levying carbon tax, the results show that when the cost of tax is greater than the cost of reducing CO\(_2\) emissions, wine industry will change the operational strategy to achieve CO\(_2\) emission reduction, and get the tax effect due to the levy of carbon tax. The results show that when CO\(_2\) taxable price:

1. At 30 US $ / metric ton - CO\(_2\), the available carbon reduction effect is 2.63%, the tax effect is 3.74 US $ / metric ton- CO\(_2\).
2. At US $ 90 / metric ton - CO\(_2\), the carbon reduction effect is 4.31% and the tax effect is US $ 6.43 / metric ton- CO\(_2\).
3. At US $150 / metric ton - CO\(_2\) carbon reduction effect is 8.59% and tax effect of US $ 19.80 / metric ton- CO\(_2\). However, due to the output constraint of the final demand, the CO\(_2\) reduction space for the wine making process that will limit the structure will be less than 10%.

REFERENCES

Shiag Chen was graduated from graduate school of Tam kung University in Taiwan in 1984. Since then, she has been a lecturer in university. She also served as Executive Secretary and Section Chief of Recruitment Department in Dan Han Institute of Technology. Now she is still teaching in Open University in Hua Lien Taiwan. Her research interests include applying engineering expertise and combining the theory and method of resource economy and management to carry out problem-oriented systematic research (including: overall and industrial aspects), taking into account both theory and practice, in response to cross-sector integration of a pluralistic society. She is currently in her last semester in Department of Resources Engineering, National Cheng Kung University, Taiwan.

Jung-Hua Wu is currently a Professor in Department of Resource Engineering, National Cheng Kung University. His research interest on specialize in engineering economy, energy economics, and project evaluation; apply engineering expertise and research on various resources such as depleting energy, renewable energy, minerals, and related industries such as electric power, petroleum, and renewable energy to conduct a systematic research.