Estimating the Impact of the MRT Elevated Railway System on Carbon Reduction in Taichung, Taiwan

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Abstract. Amid rapid global economic development and the threat of global warming, green transportation and related issues have risen to prominence in various countries. In Taiwan in 2009, Taichung was selected as a low-carbon demonstration city, in which energy conservation and carbon reduction would be actively promoted, with the wider aim of developing a green economy and lifestyle. This study explores the carbon-reduction benefits of the MRT elevated railway in the Taichung Metropolitan Area. The railway’s construction has been associated with intensive redevelopment of existing stations, but this process has been unbalanced due to railway physical. Five new stations will also be added, and belt-like spaces at ground level made available for housing and other non-railway-related purposes. Utilizing literature collection and the Analytical Hierarchy Process (AHP) research method to explore the factors affecting the efficiency of the MRT, this study reveals that the AHP weights of the main criteria for the escalation of MRT development in Taichung are 0.5833 for green transportation and 0.4167 for green environment; while in the overall ranking of the sub-criteria, the top three evaluation factors are mass transportation (0.31337), greenery planting (0.21832), and green building (0.19444).

1. Introduction
Since the industrial revolution, the world’s population and economy have grown rapidly, leading to greenhouse gas emissions and thus to global warming. The United Nations adopted its Framework Convention on Climate Change in 1992; this was followed five years later by the Kyoto Protocol, and in 2009 by the Copenhagen Accord. Many countries have embraced energy conservation and carbon reduction as new directions for their economic-development and energy strategies, in pursuit of sustainable low-carbon societies and economies. As such, it can now be said that international norms include reducing energy use and carbon emissions, mitigating climate change, and enabling global sustainability.

The World Wide Fund for Nature defines a low-carbon city as one that maintains low energy consumption and carbon dioxide emissions even under conditions of rapid economic development. The Climate Group’s definition, meanwhile, requires that such cities have low-carbon economies. In Taiwan, the goals for low-carbon cities – rooted in wider sustainable-development aims – are to
harness economic growth, environmental protection, ecological conservation, social justice and related policies to achieve multiple benefits: i.e., not merely reducing carbon emissions, but also fostering energy security and building resilience to environmental shocks. The development of mass transit can reduce the use of private cars, especially if developed in combination with bicycle networks, pedestrian walkways, and other forms of human-oriented traffic.

As part of its low-carbon strategy, the Taiwanese city of Taichung is actively promoting the development of both mass transit and human-oriented transportation. Specifically, the building of a new elevated railway system there, known as the MRT, will involve the greening and beautification of the ground-level areas previously occupied by the tracks, including but not limited to the installation of bicycle lanes and parks. At the same time, planned improvements to the stations and changes to the urban-planning regulations along these corridors (e.g., to drive the renewal of old buildings and increase the proportion of green buildings) are intended to boost the quality of life of the old metropolitan area; and a green belt along the line will be created as a living garden for residents and a focus for gradual regeneration and economic development, not merely in the city but extending into its rural hinterland. In addition, changes in the existing railway’s routes have been devised in part to green parkway.

The present study follows the lead of most railway-related research on carbon reduction, which has focused on low-carbon cities, land-use impacts, and urban-development strategies (e.g., Tu, 2000; Hung, 2010; Kusumaningrum, 2012; Lin, 2013; Wang, 2006) [1-5]. Specifically, it examines the theoretical relationships between low-carbon cities and other low-carbon indicators, and establishes the carbon-reduction benefit index of the MRT elevated railway using the Analytical Hierarchy Process (AHP).

The Taichung MRT Project stretches from Fengyuan Station in the north to Daqing Station in the south, and has a total length of 21.7 kilometers. As well as the two termini, two existing stations – i.e., Tanzi and Taiyuan – will continue in use, and five new commuter stations will be built: at Lilin, Toujiau, Songzhu, Jingwu, and Wuquan. Additionally, Taichung Station will be rebuilt on a new site, though its original building will remain as a historical monument, possibly to be repurposed as a railway museum. Songzhu Station and Daqing Station will be served by the MRT’s Green Line, and Taichung New Station by the Blue Line and Orange Line, as shown in Figure 1.

![Figure 1. MRT Elevated Railway System in Taichung schematic diagram [6]](image-url)

2. Research Methods
This study aims to clarify both the definitions and the goals of low-carbon cities and elevated railways, with special reference to the prior literature and actual rail-transit reduction plans in the Taichung...
Metropolitan Area. The literature examined for this purpose included governmental research reports, master’s and doctoral theses, online and offline newspaper and magazine articles, the European Green City Index (2009) [7], the Asian Green City Index (2011) [8], and the U.S. Environmental Protection Agency’s low-carbon city benefit assessment (2011) [9], among other relevant sources. The structural indicators used in AHP were established by Chih (2009) [10] and Yang (2012) [11] and Wu (2017) [12]. Descriptions of the research dimensions and of these indicators are presented in Tables 1 and 2, respectively.

Table 1. Taichung MRT Research Dimensions

| Dimension          | Definition                                                                                                                                 |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| Green Transportation| Development of mass transit can reduce the use of private cars. Bicycle and pedestrian-walkway networks can be designed to complement mass transit, thus achieving the maximum benefit of green traffic. This non-motorized transportation is beneficial to human health and interaction, and relatively safe, as well as an effective means of reducing carbon emissions. |
| Green Environment  | The elevation and re-orientation of the MRT will form a new axis for the city’s parks, along which renewal of old buildings, the construction of new green buildings, the creation of new green spaces, and low-carbon economic development will take place. Eventually, it is expected to extend these benefits to surrounding communities that the MRT connects. |

Table 2. Taichung MRT Carbon-reduction Indicators

| Dimension          | Impact Sub-dimension | Definition                                                                                                                                 |
|--------------------|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| Green Transportation| Mass Transit         | Five commuter stations will be added to the existing system, of which Songzhu Station and Daqing Station will serve the MRT’s Green Line, and Taichung New Station the Blue and Orange lines. In tandem with the bus system, these improvements are expected to promote residents’ willingness to use mass transit. |
|                    | Bicycle Network      | The Taichung Bicycle Road Network, based on the Taichung Heart Green Parkway bicycle road network, complement’s the city’s established public bicycle-rental system. There are also plans to create a new bicycle lane in the open space along the railway that will connect to the existing bicycle-lane system. |
|                    | Pedestrian Trail     | The elevation of the MRT above ground level will release considerable space, which will be devoted primarily to people-oriented functions. It will be connected to the surrounding area’s existing pedestrian walkway system to create a friendly and comfortable walking environment and reduce the possibility of collisions between walkers and vehicles. |
| Green Environment  | Green Architecture   | The new MRT stations are being built according to green principles, with solar panels and natural ventilation and lighting. |
|                    | Greenery Planting    | The linear open spaces that will result from the railway’s elevation will become a new “garden road” running through Taichung. Most of this space will be used as a park, other green space, and a public plaza. Once it is connected to the city’s existing Green Parkway system, it will provide a diverse
recreational environment that is expected to reduce carbon emissions.

In keeping with the present study’s primary interests in low-carbon cities and urban development, the experts surveyed as part of its AHP assessment of the carbon-reduction benefits of the Taichung MRT were recruited from the fields of urban design, ecology, and landscape planning. In this study, a questionnaire sent via e-mail. A total of 17 experts (i.e., either five or six in each of these three fields) were invited to participate, 10 of whom agreed to do so. The eight valid responses these 10 experts provided were then analyzed using Expert Choice.

3. Results and Discussion

3.1. Taichung MRT Carbon-reduction Benefit Measurement
Analysis of the expert questionnaire results indicated that the weight of green traffic (0.5872) is greater than the green environment (0.4128), the weighting difference between the two was only 0.1744, as shown in Table 3.

| Dimension           | Relative weight | Absolute weight | Ranking |
|---------------------|-----------------|-----------------|---------|
| Green Transportation| 0.5833          | 0.5164          | 1       |
| Green Environment   | 0.4167          | 0.3630          | 2       |

As shown in Table 4, the weights of the sub-dimensions of green traffic were mass transit (0.31337), pedestrian trail system (0.17269), and bicycle network (0.10117). For green environment, they were greenery planting (0.21832) and green building (0.19444).

| Impact sub-dimensions | Relative weight | Absolute weight | Ranking |
|-----------------------|-----------------|-----------------|---------|
| Mass Transit          | 0.5293          | 0.3088          | 1       |
| Bicycle Network       | 0.1694          | 0.0988          | 5       |
| Pedestrian Trail System| 0.3013         | 0.1757          | 4       |
| Green Building        | 0.4714          | 0.1964          | 3       |
| Greenery Planting     | 0.5286          | 0.2203          | 2       |

3.2. Analysis of the Weights of Carbon-reduction Indicators for the Taichung Metropolitan Area’s Overhead Rapid Transit Plan

3.2.1. Green Transportation. Our review of the prior literature on green transportation suggests that, while the development of mass transit is critically important, people-oriented transportation should never be overlooked, as it can dramatically increase the convenience of living in urban areas by widening access to all areas (mass transit facilities included). Moreover, the convenience of mass transit frequently leads to increases in the overall number of trips people make; and if there is no effective plan for moving people from their homes to the trains, and from the trains to their eventual destinations, the net effect of rail improvements might actually be increased congestion. From the perspective of long-term urban development, therefore, the completely integrated planning of mass transit and human-traffic routes will increase the efficiency of the city, reduce waste, and effectively achieve the goal of carbon reduction.
3.2.2. Green Environment. Although the weighting that the experts assigned to the green-environment dimension is lower than the one they assigned to green transportation, the importance of its contribution to the Taichung MRT program’s carbon-emission reduction effort was still strong. Guided by the overarching goal of reinventing itself as a low-carbon city, Taichung has built a ring road and incentivized the construction of green buildings. Parkways connect small local green spaces to larger parks, forming a green network that mitigates the air pollution and carbon reduction while providing a space that is sociable, environmentally friendly, energy-saving, healthy and in harmony with the area’s natural ecology.

3.2.3. Mass Transportation. The prior literature has often advanced arguments that public transport is the key factor in urban carbon reduction, and this study’s panel of experts indeed gave mass transit a much higher weighting (0.31337) than either the pedestrian-walkway system (0.17269) or the bicycle network (0.10117).

Proceeding from the concept of sustainable urban development, it is reasonably clear that high-efficiency mass transportation systems are the backbone of high-quality, sustainable urban development, and important drivers of the use of human-powered transportation and reductions in the use of private motor vehicles (Du, 2000). After the Taichung MRT project is completed, the new station and the MRT Green Line will be shared, which as well as improving the metropolitan area’s mass-transit network will effectively encourage its people to reduce their carbon emissions.

3.2.4. Greenery Planting. The category of greenery planting includes green spaces and parks. As briefly noted above, the area beneath and beside the 21.7-kilometer route of the Taichung MRT will become the new Green Parkway in Taichung City, in tandem with the original Green Parkway in Taichung Metropolitan Area. Green spaces and gardens in cities have become important tools for regulating climate and reducing carbon. The canopy of trees in the city can intercept, reflect and absorb solar radiation; and evaporation from trees and other plants can also absorb heat, mitigating the urban heat-island effect. In addition to the linear open space on the ground that will be made available due specifically to the elevation of the railway, open space will be cleared on both sides of each station to reduce the system’s overall impact via greening. Planning restrictions can ensure that it will be used as a greenbelt in combination with the space once occupied by the original railway, and thus connect surrounding areas into a new low-carbon living circle.

3.2.5. Green Building. All building work associated with the MRT project – including repair and renewal, as well as new construction – will be conducted on green-building principles. It is anticipated that the completion of each new or refurbished station will revitalize the surrounding area, with existing buildings being given the opportunity to be renewed, repaired or rebuilt using green methods and green building materials, and guided by the design principles of energy saving and carbon-emissions reduction. The plan’s inclusion of historical preservation of some station architecture will bring about further opportunities for development and redevelopment of the adjacent area.

3.2.6. Pedestrian Trail System. Fairly small changes to the human environment can have large impacts on the use of mass transit, and thus on the greening of transportation in general. In recent years, Taichung’s planning officials have actively promoted human-oriented road spaces, amid a shift in the overall emphasis in the development of urban space and transportation from efficiency to liveability. In addition to their basic function of moving people and goods from place to place, urban transportation services are increasingly expected to meet the requirements of humanization and environmental protection, and attract a greater share of the public to use mass transit. In recent years, amid increases in air pollution caused by railway engines and the negative impact of global warming, people are paying ever more attention to the concept of perseverance and re-engaging with the concept of green transportation. In the development of low-carbon cities, people-oriented transportation is assigned a high value, due to its environment-friendliness and sustainability. Pedestrian walkway
systems emphasize freedom, convenience, accessibility, aesthetics, safety, comfort and sustainability. Among such systems’ sustainability and comfort indicators, factors such as green coverage, plant diversity, and planting green beautification are frequently mentioned; and because – if done right – walkways can both enhance interaction between communities and connect people to mass transit, thus enhancing their willingness to use it, perfecting the pedestrian system is one of the most important tasks of mass-transit design and construction.

3.2.7. Bicycle Network. Taichung’s bicycle lanes and its plans to construct others are discontinuous, and there is currently no mechanism for creating a single, connected bicycle road network there. Nonetheless, recent years have seen active promotion of the bicycle network’s development as a green corridor connecting the Taichung Central Life Circle to commuter transportation and recreation areas, as an intrinsic part of the emerging green corridor network. However, it is clear that despite people’s extensive use of bicycles for leisure purposes, they are not used for commuting in Taichung, so it is perhaps unsurprising that the nascent bicycle network’s carbon-reduction benefits were assigned the lowest AHP weighting among all the factors this study examined. If the overall bicycle network is eventually perfected to the point that Taichung’s residents can use it as a continuous commuting route, it will become a viable alternative to both mass transit and personal motor vehicles, and thus make an important contribution to carbon reduction in the city. The public bicycle-rental system was implemented specifically to encourage short-distance use of this low-mode of transportation, not only to reduce environmental pollution and energy use, but to mitigate urban road-traffic congestion by reducing demand for the ownership and use of private motor vehicles.

4. Conclusion
Based on a literature review and an AHP panel study, the present work has explored the carbon-reduction impact of Taichung’s MRT elevated-railway project. The results suggest that the impact structure of the MRT on carbon-reduction benefits consists of two major facets: green transportation and green environment. These in turn can usefully be divided into a total of five evaluation factors: i.e., green transportation into mass transit, bicycle networks and pedestrian-walkway systems; and green environment into green buildings and greenery planting.

Although the AHP weighting assigned to green transportation (0.5872) was greater than that of green environment (0.4128), the weighting difference between the two was relatively small. This implies that the development of green transportation must proceed in tandem with green-environment initiatives if the city and metropolitan area are to effectively achieve their carbon-reduction goals.

The carbon-reduction benefit index was highest for mass transportation, with an absolute weight of 0.31337. The next highest was for greenery planting, at 0.21832. The third- and fourth-ranked positions went to green building (0.19444) and the pedestrian walkway system (0.17269), while by far the lowest absolute weight was assigned to the bicycle network, at 0.10117.

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