MobilityCoins - Navigating the Complexities of Tradable Credit Schemes

Philipp Servatius*
Chair of Traffic Engineering and Control, Technical University of Munich, Germany
Email: philipp.servatius@tum.de

Allister Loder
Chair of Traffic Engineering and Control, Technical University of Munich, Germany
Email: allister.loder@tum.de

Klaus Bogenberger
Chair of Traffic Engineering and Control, Technical University of Munich, Germany
Email: klaus.bogenberger@tum.de

* Corresponding author

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ABSTRACT

Tradable credit schemes have emerged as a promising approach to travel demand management. Literature covers tradable credit scheme affected travel behavior very well, but it has largely overlooked their potential from a merely quantitative perspective. In this paper, we focus on defining the underlying of a tradable credit for the matter of a net-zero transition of the transportation system. A multi-modal, multi-period perspective allows the sizing of a Tradable Credit Scheme to real-world scenarios. In general, credits hold several information: (i) the credits' underlying physical meaning like carbon emissions or other external costs, (ii) monetary value via the market price, and (iii) traveler utility information. This study focuses on the first category and explores how tradable credit schemes can influence and guide mode-choice decisions across multiple periods to achieve greenhouse gas emission targets. An agency has two options in order to achieve that: reducing the allocated number of credits and adjusting mode-specific prices for trips. Furthermore, Our paper presents a mathematical model illustrating this concept based on real-life data from the city of Munich, answering the question how tradable credits can be balanced when applied in a real-world scenario. In the forthcoming years, the transition from internal combustion engines to electric vehicles will lead to a reduction in energy tax revenues for the German tax authorities. An approach to compensate for this gap using Tradable Credit Schemes is also illustrated. The method can be easily applied to other metropolitan regions, which the authors highly welcome.

Keywords: sizing tradable credits; demand management; congestion mitigation

INTRODUCTION

Transport sector requires economic instruments to achieve climate targets and limit traffic externalities. However, economists have had only limited success in promoting effective economic measures (*1*). Tradable credit schemes (TCS) are considered promising instruments. As cap-and-trade systems, they allow to set outcomes overall emission targets and people collectively distribute those resources efficiently. TCS, as they can be found in literature so far, cover mobility and market features. Those measures reflect short-term decisions by users. Either credits are used to fulfill mobility demands or are traded on the market to get another currency in return for a specific market price. Thus, TCS remain a traffic and travel demand management scheme (*2, 3*).

We extend the canonical TCS idea (*3, 4*) to the MobilityCoins System (*5*). The latter argues to use credits not only for charging for externalities, but also to use them as incentives for sustainable travel choices and to use credits to partially fund transportation projects. The economic and social motivation of this link is that travelers not only state their preferences on how the transportation system be designed, but also can travelers inform decision makers about where to prioritize measures to improve their lives, not only traffic. We establish the link by allowing travelers to *crowdfund* the funding gap between costs and benefits of an otherwise not realized transport project, e.g., a new bus line, through redeeming their credits for the project instead of travel or trading them on the market. In this regard, MobilityCoins can be considered as a moderator between the short-term traffic and travel demand management on one side and the long-term cost-benefit-appraisals for transport projects on the other hand. A well balanced scheme is the precondition of the additional feature. In this paper, we are presenting a new quantitative perspective on TCS that aligns real world data with the same and supports the calibration of the scheme. Furthermore, sizing the scheme to demand data of Munich brings the idea closer to a real world application. To explore this research question, we develop a mathematical framework of the MobilityCoin System in this paper, beginning with the mobility segment.

This paper proposes a trial and error method for selecting optimal credit schemes in general networks without relying on demand functions, using observed link flows at traffic equilibrium and revealed credit prices at market equilibrium to update credit charging schemes and credit distribution amounts (*6*). It is organized as follows. We first review the literature on TCS. Thereafter, we introduce the MobilityCoin System and set the general frame for this paper. We then demonstrate the basic mechanism and quantitative flow to align the parameter of the System with real-world data from Munich. We close this paper with a discussion and a outlook for future research.

STATE OF THE ART

Based on the idea of TCS, first introduced by (*2*), we propose an extended generic policy instrument. As depicted in Figure 1, every user receives an initial credit budget at the beginning of each period which can be utilized in three main ways: mobility (demand), market (trading) and crowdfunding (supply). First, for mobility, credits can be used for a trip while charges depend on expected externalities. Second, instead of spending credits on mobility, they can be traded among users of the system. Due to the limited supply of credits, a market price is established that serves as an economic incentive to encourage the adoption of environmentally friendly, less expensive modes of transportation. Once users run out of credits, they have the choice to buy additional credits on the market, while users with a surplus in credits can monetize them. Third, credits can also be invested in supply-side measures defined by the agency to improve the travelers' generalized cost of travel, e.g. free flow speed improvements. The latter also gives users the opportunity to actively participate in the supply-side design, which can improve public support for such a policy tool (*7*)(*8*). Public acceptability of carbon pricing can be further improved through a tangible application and proper utilization of the revenues raised, e.g. for the crowdfunding of infrastructure (*9*). However, the idea of crowdfunding public infrastructure is not new and already present in the sustainable energy sector (*10, 11*). It has also been reported a few times in transport, e.g., public transport (PT) (*12*) or for bicycle infrastructure (*13*), but as yet it remains a niche.

Tradable credit schemes

As mentioned before, the novel approach goes back to the idea of a tradable credit schemes (*14*). It is a cap-and-trade system for mobility, which originally refers to (*15*). (*2*) were the ones who originally suggested using tradable credits in road traffic management. In general, a distinction can be made between tradable credit schemes and mobility permit schemes. The former entails that qualified users receive an initial credit budget from which they pay the charges for any of their trips (*14*). The latter requires that travelers have to bid for or buy the necessary permits for a specific link (e.g. a bottleneck) within a specific time period (*16*). (*17*) was one of the first using tradable permits to control vehicle emissions, congestion and urban decentralization and (*3*) were the first to algebraically express tradable credit schemes in small transportation networks. In recent years, numerous methodologies with varying characteristics in terms of user heterogeneity, validity, or allocation emerged and were applied to various kinds of networks. While certain schemes permit the transfer of remaining credits to the upcoming period, the majority of schemes contemplate a smaller period of expiration. Above all, in theory, tradable credits proved successful in achieving a congestion reduction goal (*3*)(*18*), and could also help to meet climate targets (*19*). While describing it as a potential promising (theoretical) instrument, (*20*) highlight that a TCS for mobility is still far from applicable to our present mobility system. (*21*) associated a TCS with congestion pricing to uphold government revenue streams. Incorporating the transportation supply side, (*22*) applies a TCS with steps to increase road capacity and (*23*) combined a TCS and link capacity improvement measures in a bi-objective bi-level model to compare economic growth and environmental management. (*24*) analyzed travel demand management for an autonomous vehicle enabled TCS and lane management strategies to reduce overall travel time under user equity constraints. (*25*) focuses on market design aspects such as allocation/expiration of credits, rules governing trading, transaction fees, and regulator intervention.

Every TCS system is targeting one or several objectives. It is not just congestion that is taken into consideration when determining the overall allocation and mobility pricing. In order to reduce greenhouse gas (GHG) emissions, the system can also be configured to influence emission externalities. (*26*) introduced market-based implementations for emissions standard attainment proposing origin-destination based pollution permits. (*27*) worked on a TCS system that redistributes link flow patterns to obtain minimum emissions for the whole network, and extend it to bi-objectives (low emissions and low travel times). (*28, 29*) considered a vehicle type specific and OD-based credit allocation in a multi-period TCS framework. In addition, they suggested a pricing structure based on the type of vehicle (zero-emission versus internal combustion engine vehicles) and the links travelers are using linked to their vehicle type. The latter work encourages the use of zero-emission vehicles, while the former redistributes flows to achieve a dual goal of minimum emissions and minimum travel time.

However, the initial endowment of credits plays a crucial role in determining the distributional and equity implications of the scheme, as it may disproportionately benefit or burden certain socio-demographic groups, especially for this paper. In this section, we discuss the importance of different initial credit allocation methods and their implications on equity. Uniform allocation distributes an equal amount of credits to each participant or user of the system. This method is straightforward and easy to implement with a broad application in research (*3, 28, 30–35*). But it may not accurately reflect the diverse needs and consumption patterns of different socio-demographic groups. For instance, low-income households may use fewer resources and be left with excess credits, while high-income households may require more credits to maintain their consumption levels, respectively travel behaviors. The result is that low-income households could potentially sell their excess credits to households with higher travel demand, thus generating revenue but also possibly reinforcing existing inequalities(*36*). Free allocation is also often used to study the effects of TCS (*37–41*). Historical allocation or grandfathering takes into account past consumption patterns or emissions to determine credit allocations. This method may appear to be fair, as it acknowledges past behavior and the resulting environmental impacts. However, historical allocation may also perpetuate existing inequalities and disproportionately benefit wealthier user, as they often rely on higher resource consumption rates, respectively emissions. Thus, low-income and vulnerable populations may receive fewer credits and face greater constraints in meeting their basic needs. Needs as well as origin-destination based allocation takes into consideration the specific circumstances and requirements of different socio-demographic groups, ensuring a more equitable distribution of credits. This method may involve adjusting credit allocations based on income, household size, distance to the work place, or other relevant factors. By tailoring credit allocations to the needs of different groups, a needs-based approach can help mitigate existing inequalities and promote environmental justice. However, this method may be more complex to implement and could require additional resources for data collection and administration(*31, 42*). The most elaborated allocation pattern in terms of complexity is the user specific distribution, reflecting the single individuals' characteristics (*14, 31, 42–44*). The choice of initial credit allocation method in tradable credit schemes has significant implications for equity among different socio-demographic groups. Uniform allocation may be easy to administer, but it may not account for diverse needs and consumption patterns. Historical allocation acknowledges past behavior but may perpetuate existing inequalities. A needs-based approach promotes environmental justice by adjusting allocations to suit the needs of different groups, but it requires more data and administrative resources. Policymakers must carefully consider the trade-offs between simplicity, fairness, and equity when designing tradable credit schemes.

The various sorts of initial endowment has a direct impact on the mobility prices which is explained in more detail later on. Literature gives insights about the perception of different pricing schemes. (*8*) investigates public perceptions of tradable peak credits (TPC) as a congestion pricing measure. The study uses focus groups with Dutch citizens to examine attitudes towards TPC in comparison to peak charge (PC) in a hypothetical city. The findings reveal that most participants preferred PC over TPC, with skepticism towards TPC being prevalent. This paper investigates the effects of travelers' perception errors on credit prices and explores how to accommodate these errors through appropriate scheme design (*36*). Due to the uncertainty in travel demand and supply in transportation infrastructure over the long term, accurate forecasts of future credit prices (CPs) cannot be provided by the central authority to travelers. This results in varied perceptions of future CPs among travelers, affecting their decisions to use or transfer credits. Travelers also perceive credit purchases as losses and sales as gains. Numerical experiments by (*45*) show that when the difference between travelers' perception of future CPs and actual CPs increases, the effectiveness of the system optimal multi-period TCS design in minimizing total system travel time decreases, unless this difference is explicitly factored into the design. Additionally, if the CA raises emission standards under the TCS design, travel costs increase.

THE MOBILITYCOIN SYSTEM

This section introduces the MobilityCoin System. The MobilityCoin represents a novel and comprehensive system that aims to manage multi-modal urban transportation. It is a tradeable credit scheme that covers the entire trip and seeks to optimize the supply and demand side of mobility in metropolitan areas. The MobilityCoin serves as a holistic instrument for the transportation system. The two key innovations are the central agency's ability to offer incentives for single modes to catalyze mode-shift and the user option to spend parts of the budget for infrastructure improvements instead of using them solely for mobility or monetizing them. Latter enables user to crowdfund for improving their quarter. These innovations distinguish the MobilityCoin System from the initial concept of tradable credits. It is illustrated in figure 1.

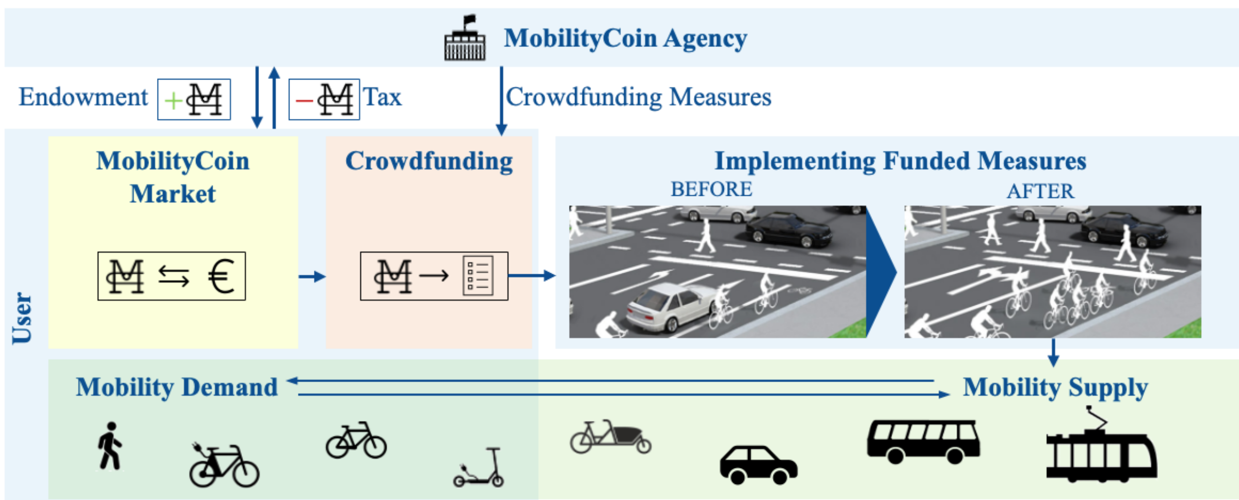

FIGURE 1 : Major building blocks of the MobilityCoin System (*5*).

Introducing the MobilityCoin System

As aforementioned, the overall objective of the MobilityCoin System is the mitigation of GHG emissions. This builds the quantitative core during the sizing of the scheme. Every additional possibility to spend coins can be expended based on this framework. Thus, we will focus mainly on the mobility part of the MobilityCoin System.

Every user of the MobilityCoin System is given a budget of MobilityCoins. The decision-making process of the users begins with a pre-trip decision, which involves selecting the mode of transportation for the upcoming trip, deciding on the route and start-time window, and considering the trip costs. These can be positive or negative depending on the externalities caused, such as GHG emissions. A negative price indicates a payback, which serves as an incentive for choosing greener modes. This encourages users to carefully consider their mode of transportation, switch to more eco-friendly routes, or adjust their departure times, all of which are essential goals of the MobilityCoin System. Thus, the system aims to optimize the existing options rather than instigate fundamental transformation. Aiming on effectiveness in the short term.

The MobilityCoin System suggests an initial coin allocation based on the following assumptions: The agency issues the coins through free allocation, and the total quantity is limited by an emission reduction target. The decision to use free allocation is based on its potential to enhance the system's social acceptability and reduce its complexity (*4*). The individual coin allocation for each user is determined by personal attributes, such as health (e.g., an allocation bonus for mobility-impaired individuals), accessibility to public transport, and the balance between jobs and housing. Work-related trip frequency or necessity is not factored into the allocation process, as companies may receive specific coin budgets for their employees. Eligible recipients of the coin budget are individuals residing within the predetermined system borders (e.g., a metropolitan area) who are over 18 years of age. The budget is valid for one year to align the system with other societal systems, such as insurance costs and tax declarations, and cannot be accumulated over consecutive years. The budget expires after one year, and the allocation process begins anew. Users must use their coin budget to pay for the external costs of trips using all eligible modes in the system, such as cars, public transport, bikes, and sharing services.

A MATHEMATICAL FRAMEWORK TO SIZE THE MOBILITYCOIN SYSTEM

In this section, we present the foundations of our study by systematically addressing the key components of our analysis. Our goal is to provide a clear understanding of the underlying framework, setting the baseline, the forecast of upcoming years by our model, and a specific case study focusing on data from the city of Munich. To achieve this, we have organized this section into four distinct subsections. In the first subsection, "assumptions," we introduce the theoretical basis of our research and outline the assumptions that have been made to support our analysis. We discuss the key principles and concepts that guide our approach, as well as the limitations imposed by these assumptions. The second subsection, "setting the status quo," delves into the process of setting the baseline that serves as a starting point for our subsequent investigations and forecasts. Next, in the "forecast based on the model" subsection, we present the predictive model we have developed, which incorporates the framework and assumptions mentioned earlier. We explain the methodology employed in creating this model, and present the results of our simulations. By analyzing these forecasts, we aim to gain insights into the potential future developments in the field. Finally, the "Munich Case" subsection presents a detailed examination of our model's application to a specific context, in this case, the city of Munich. We discuss how the general findings and forecasts are manifested in this particular scenario, highlighting the unique challenges and opportunities that arise in the Munich context. This case study serves as a practical illustration of the applicability and relevance of our model to real-world situations.

Sizing objectives

The sizing of the MobilityCoin system follows two key objectives.

- Meet decarbonization goals over the system's planning period, incremental adjustment of greenhouse-gas target gap Δ
- Generate revenue R for treasury from a transaction fee to replace loss in revenue from the energy tax δ_r. The objective is to minimize the difference between loss and R

Assumptions

The mobility price function determines the trip costs, p_{ext}, which will be charged in MobilityCoins. The price is usually known in advance and is defined by the agency. The function depends on

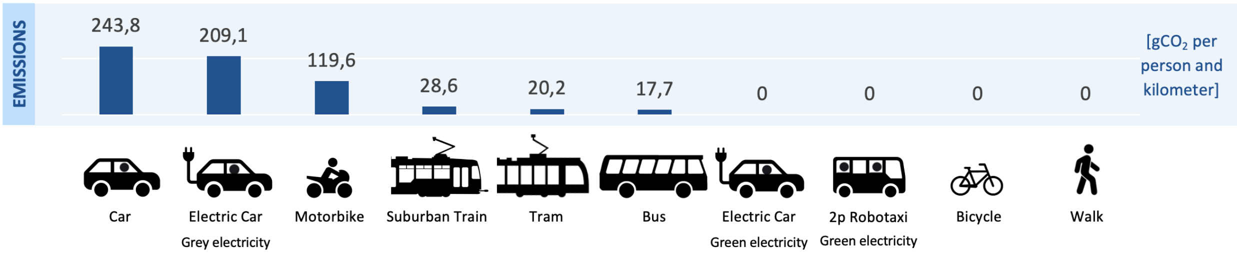

FIGURE 2 : Specific emissions for different modes of transport (*46*).

several variables and parameters, as described by eq. 1, and includes the distance of the trip (d), the state of the transportation system at the time of the trip, and the mode-specific parameters of emissions ($m(e)$).

$$p_{\text{ext}} = f(d, m(e)) \tag{1}$$

To thoroughly design the MobilityCoin System, we develop a comprehensive quantitative analysis framework that encompasses a set of well-defined assumptions. Assumptions are an integral part of the scientific process, as they allow us to simplify complex systems and formulate hypotheses. In our case, assumptions are necessary due to the limitations of our current knowledge or technology, since no TCS is in place so far.

We have designed the MobilityCoin System to subsidize user groups below the age of 18 and above 65. Consequently, our forecasts are calculated with a focus on the user group between the ages of 18 and 65, taking into account the potential effects of these subsidies and consider that users who are not part of this group aren't affected by the system, leading to a minor change in their travel behavior.

Table 1 summaries the indices, parameters and variables.

Setting the baseline

First, we have to select a reference year to start gathering data. Assuming that in the base year ($y = 0$) the amount of travel by mode m in terms of kilometers is $T_{m,y}$. Every mode of transport has specific carbon emissions e_m, measured in units grams carbon dioxide equivalent per kilometer. The model relies on two major inputs: the person kilometers by modes as well as the respective GHG emissions caused. Based on those values we can compute the ratios between network demand, GHG emissions, and number of coins. Therefore the agency has to allocate MobilityCoins. In the first year, $y = 0$, treasury obtains a tax revenue R from fuel excise taxes. Due to the targeted electrification and the mode shift, this revenue decreases in absolute terms from year to year by δ_r.

$$\delta_r = \lambda_{tec} + \lambda_{ms} \tag{2}$$

Initial coin allocation

MobilityCoins can be allocated in a variety of ways as already mentioned above. We chose an uniform allocation since we want to focus on the basic principles first with homogeneous user as aforementioned.

With the allocation of coins, the specific GHG emission ratio is set. The agency can basically decide freely about the amount of coins I_{agency} to be endowed. This has effects on the

Set	Definition	
Y	Years considered in the forecasting, where $y \in Y$	
M	Modes considered in the forecasting, where $m \in M$	
Parameter	**Definition**	**Unit**
$T_{ref,m}$	Total mileage in reference year for mode m.	[pkm]
$E_{ref,m}$	Total emissions in reference year for mode m.	[gCO_2e]
$E_{tar,m}$	Total target emissions in reference year for mode m.	[gCO_2e]
e_m	Specific GHG emissions for mode m.	[gCO_2e]
f	Transaction fee.	[%]
I_{total}	Total number of coins generated in a period.	[u]
I_{agency}	Initial MobilityCoin endowment.	[u]
$I_{incentive}$	MobilityCoins from incentives.	[u]
p_{ext}	MobilityCoin externality ratio (gCO_2e).	[coin/ext]
γ_m	MobilityCoin incentive for mode m.	[u]
δ_r	Energy tax revenue gap.	[EUR]
Δ_1	Target gap between status-quo and target.	[pkm]
Variable	**Definition**	**Unit**
Δ_2	Overshoot to ensure reaching the target as a function of Δ_1.	[pkm]
$E_{res,y}$	Resulting emissions in reference year for mode m.	[gCO_2e]
$E_{total,m}$	Total emissions in forecast year.	[gCO_2e]
$I_{res,y}$	Resulting coins based on mode-shift for year y.	[u]
R	Revenue generated from transaction tax.	[EUR]
θ_y	Percentage of mode-shift from MIT to PT.	[%]
λ_{tec}	Revenue loss due to new technologies.	[EUR]
λ_{ms}	Revenue loss due to mode-shift.	[EUR]
$\mu_{result,m}$	Total mileage in forecast year for mode m.	[pkm]
τ_{market}	MobilityCoins traded on market.	[u]

TABLE 1 : Indices, parameters and variables.

respective carrying externality value and subsequently on prize determination. Latter has major effects on the user perception as mentioned in section 2.1. In addition, the agency has to consider coins generated from incentives for active mobility $I_{incentive}$. Taken together, these make up the total number of credits in circulation which is shown in eq. 3.

$$I_{\text{total}} = I_{\text{agency}} + I_{\text{incentive}} \tag{3}$$

While I_{agency} is allocated at the very beginning of each period, $I_{incentive}$ is growing over time. It is crucial to balance the incentives soundly. The higher the incentives, the more externalities can be caused within the system framework and the main goals can possibly be overridden. The probability of occurrence can be determined by high quality past data.

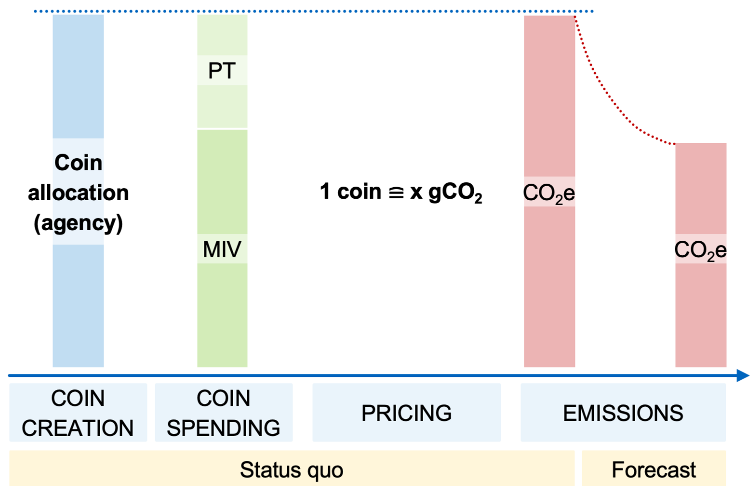

FIGURE 3 : Quantity structure.

Forecast

Building on the aforementioned assumptions, we forecast GHG emissions, shown in eq. 4, by examining the feasible adjustments that the agency can make. Total emissions E_{total} result from the total mode-specific mileage $\mu_{result,m}$ and the respective emissions e_m. These adjustments include the reduction of coins by lowering incentives or endowment, and the modification of the emission based MobilityCoin price. By analyzing these factors, we can effectively compare our results with future emission targets, providing valuable insights into potential future scenarios.

$$E_{\text{total}} = e_{\text{PT}}\mu_{\text{result,PT}} + e_{\text{MIT}}\mu_{\text{result,MIT}} \tag{4}$$

This forecasting approach enables us to simulate various scenarios and refine the system parameters to achieve GHG emission targets as well as revenue R to compensate said energy tax losses. Through these simulation, we can better understand the potential impacts of different agency adjustments on GHG emissions and develop a more effective MobilityCoin System that aligns with our goals of promoting sustainable transportation.

In addition we integrate a mode-choice module that alters the person kilometer based PT/MIT ratio. This allows the determination of person kilometer percentage θ_y that has to be shifted from MIT to PT in order to achieve emission targets and conversely provides information on the maximum number of coins that can be endowed.

To calibrate the fundamental behavior of the MobilityCoin System, we describe the system mathematically.

The amount of traded coins result of the overshoot Δ_2, the mode specific emission parameters ε_{MIT} and ε_{PT} as well as the coin-emission-ratio ρ_{CO_2e}, following eqn. 5.

$$\tau_{market} = \Delta_2((\varepsilon_{MIT} - \varepsilon_{PT})\rho_{CO_2e}) \tag{5}$$

Revenue is generated through a transaction fee f that is applied on the number of coins exchanged on the market τ_{market} shown in eq. 6.

$$R = \tau_{market} * f \tag{6}$$

Our intention is to deliver a clear recommendation with respect to achieving two key objec-

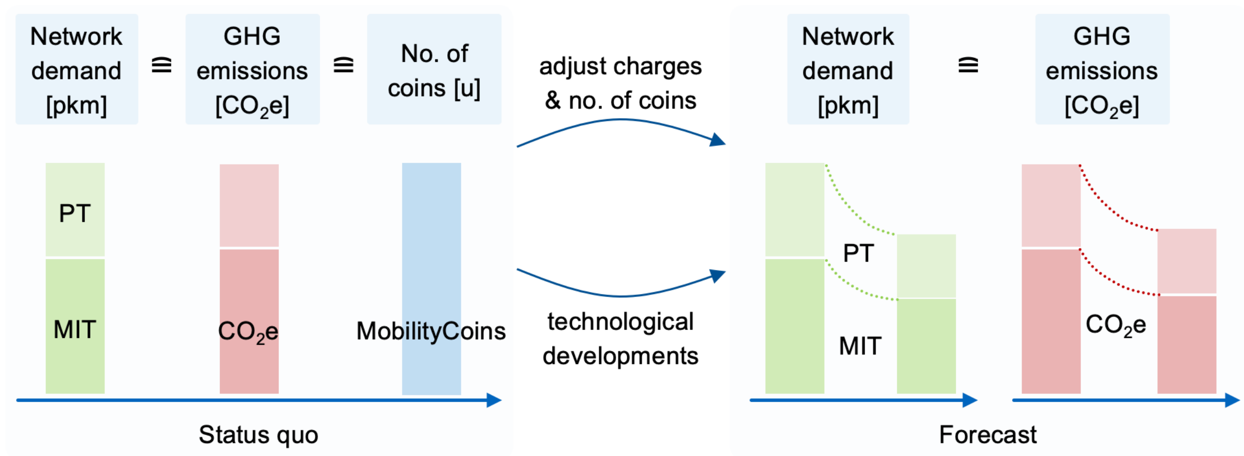

FIGURE 4 : Calculator method.

tives: decarbonization and revenue generation. Our approach seeks to harmonize these objectives, pursuing a revenue-neutral path to meeting our climate goals. Revenue neutrality means a compensation of lacking energy tax. We recognize that achieving a balance between these often competing priorities can be complex, and thus we present a structured methodology for determining the optimal settings for the system. The outlined methodology offers insights into which system configuration should be preferred to accomplish these twin objectives most effectively. By following this approach, we believe it is possible to simultaneously advance towards our environmental goals while ensuring financial sustainability.

MUNICH APPLICATION

Building on our previously shown methodology, we turn our focus to the city of Munich for its application. Those provide us with a solid foundation for understanding recent patterns and forecasting future trends.

Data used for calculating future scenarios

The model we employ in our study relies on data from past years, collected from various sources, which has been carefully aligned and smoothed to ensure consistency. The analysis uses data shown in table 1. When calculating possible mode-choice effects, we initially consider a homogeneous user population as shown in table 3. While it is evident that individuals react differently to adjustments made by the agency in terms of pricing and endowment, we do not account for these differences when explaining the basic principles of the model. We account for induced demand due to incentives for active modes of transportation by incorporating a 3% increase in demand per year. As for the target curve, we describe the transition from the baseline to the target as exponentially decreasing. Additionally, our model considers technological developments that underlie specific greenhouse gas (GHG) emissions, which encompass both the means of transport and the upstream processes (well-to-wheel). The proportion of battery-electric vehicles is taken into account as well.

Prior to introducing the assumed Munich scenario, we give an overview about the underlying data. Given the context, respectively city-specific nature of the MobilityCoin System's governing parameters, it is necessary to identify the same for each application by conducting a thorough assessment of the current situation.

Munich Parameters	Values	Definition
T_{MIT}	12,191,000,000 [pkm]	Total mileage of motorized individual transport (*48*).
T_{PT}	7,993,500,000 [pkm]	Total mileage of public transport (*47*).
T_B	1,131,500,000 [pkm]	Total mileage biking (*47*).
T_W	620,500,000 [pkm]	Total mileage walking (*47*).
$E_{ref,MIT}$	3,300,000 [tCO_2e]	Total MIT GHG emissions for reference year.
$E_{tar,MIT}$	1,500,000 [tCO_2e]	GHG emissions targets for MIT.
$E_{ref,PT}$	131,692 [tCO_2e]	Total PT GHG emissions for reference year.
$E_{tar,PT}$	40,129 [tCO_2e]	GHG emissions targets for PT.

TABLE 2 : Model parameters.

We extend the model to the mode-shift case as follows. On the demand side, we use the existing demand for MIT and PT provided in (*47*).

Market dynamics and revenue

The quantity of available coins has direct impact on market dynamics, which is discussed in this section. This interrelation between coin count and market behavior becomes more clearly under scenarios of increased market pressure. Trades are bound to happen even when coins are distributed uniformly, largely due to the heterogeneous nature of user interactions with the system - even if the number of coins were theoretically sufficient for the demand in the system.

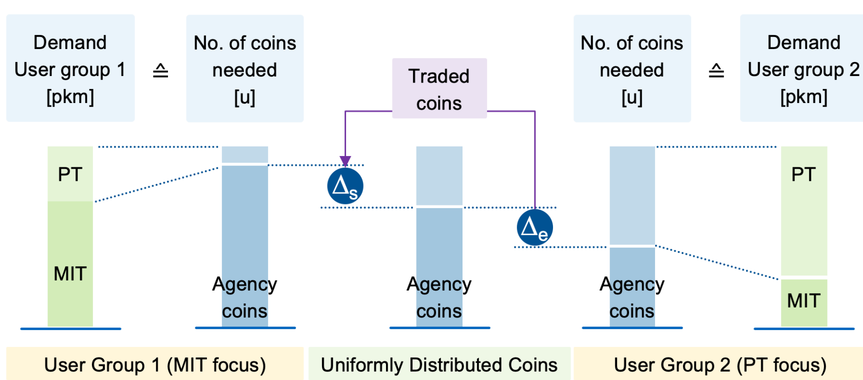

FIGURE 5 : Cause of coins to be traded - Δ_e excess, respectively Δ_s shortage per user group.

The methodology for determining the quantity of allocated coins stems from the past values for PT and MIT. This quantity is not static. It undergoes reduction and averaging with the aim of achieving future targets. However, the effects of this approach are not felt evenly across the user spectrum. Certain user groups, notably those focused on MIT, are likely to experience a shortfall of coins. Conversely, other groups might find themselves with an excess of coins which is simplified visualized in fig. 5. This discrepancy in coin allocation among various user groups inherently introduces disequilibrium into the system. A heightened market stress intensifies the necessity for trades, a phenomenon which will be divided into a two-step process: (i) reduction of coins to the emissions target value and, (ii) an additional reduction of coins to underrun the target in order to reach the target despite trading.

In the first step, the quantity of available coins is reduced, deliberately targeting the emissions goal. This action inevitably generates pressure on the market, as the decrease in supply fails to meet the status quo demand. In fig. 6, we have depicted the resulting equilibria that arise from the intersections of the coin demand function with both supply functions, before and after tightening of credits. Consequently, the users of the system are either forced to adapt to alternate modes of operation, or buy additional coins to extend their range by car. It is crucial to note that the need for these shifts stems directly from the imposed scarcity of coins, thereby directly linking the reduction of coins with market dynamics. That is based on the fact that specific mode charges per kilometer of MIT exceed the specific mode charges for PT due to higher externalities. Thus, a one-to-one exchange in PT passenger-kilometer to MIT passenger-kilometer is not feasible.

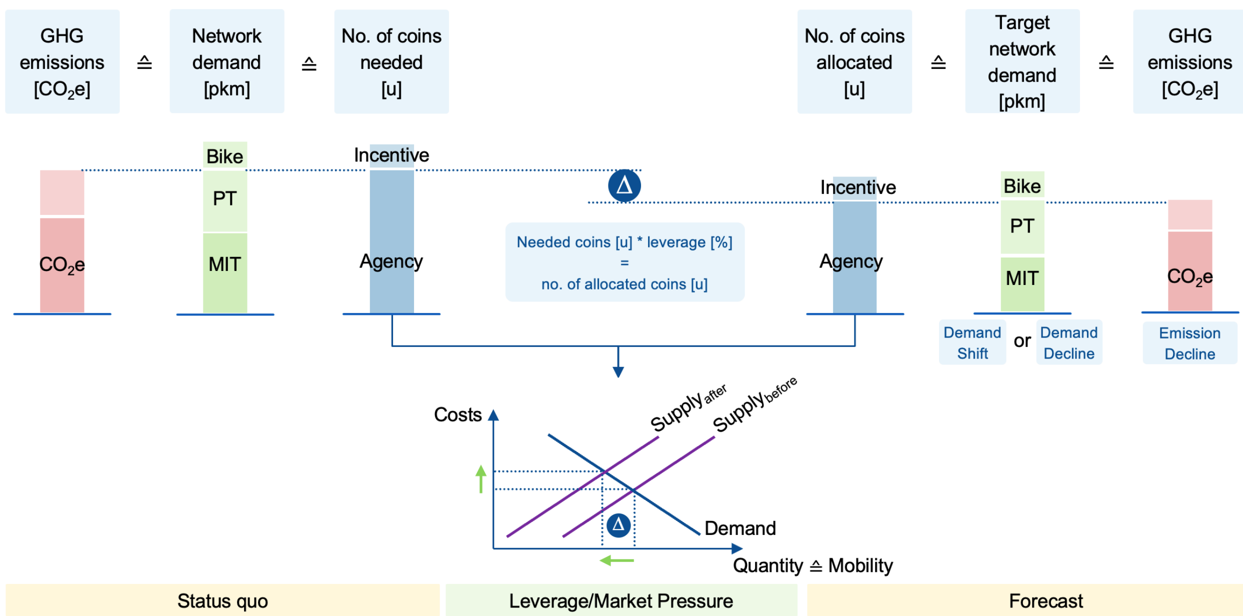

FIGURE 6 : Tightening of credits.

The second step involves an additional reduction in the number of coins, thereby creating a deliberate overshoot concerning the initial target. This further reduction amplifies the pressure on the market, as the supply becomes even more inadequate to meet the demand. Again, this elevated pressure propels users to seek other operational modes and trading strategies.

Over the course of time, as progress is made towards reaching the targeted goals, there is a noticeable decrease in Δ_1. This reduction is significant as it directly corresponds to a contraction in revenue, as shown in fig. 8. Such a trend highlights the dynamic interplay between goal attainment and the financial implications within the system. It also suggests a potential challenge in maintaining revenue levels while advancing towards the defined objectives, a consideration that may necessitate strategic adjustments within the system's implementation or operation.

Furthermore, the trading activity of users aiming to acquire additional range for their car mode still results in a convergence towards the target value from below. While these trades are triggered by the need to adapt to the reduced number of coins, they inadvertently contribute towards the achievement of the emissions goal. Thus, through a designed strategy of reducing coin

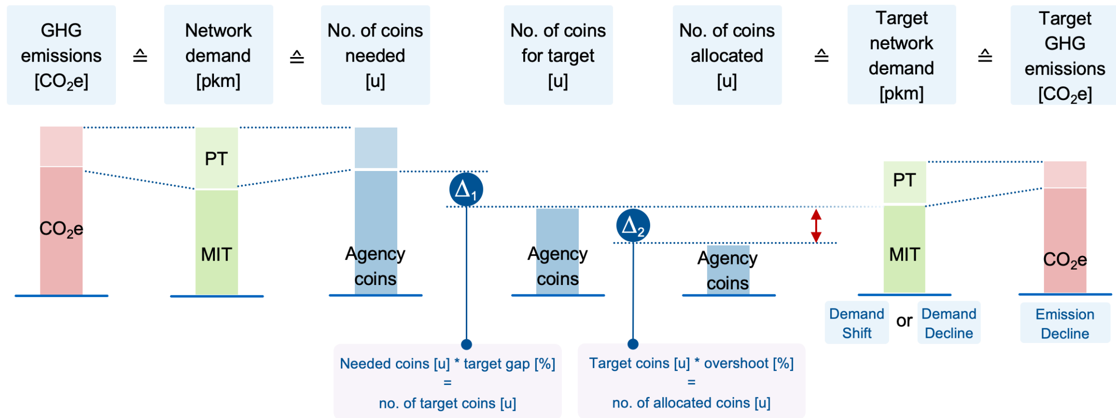

FIGURE 7 : Visualization of Δ_1 and Δ_2 to create number of traded coins.

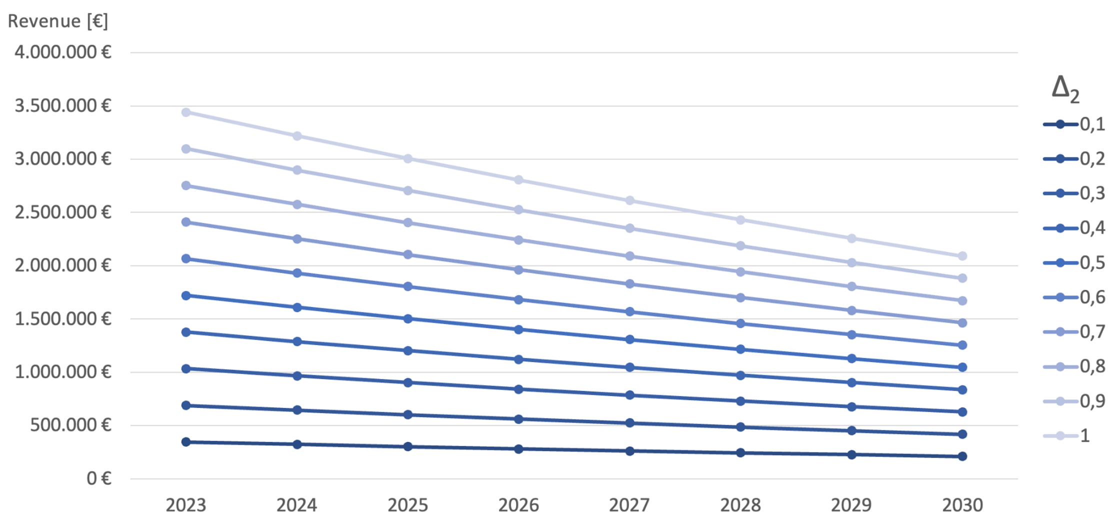

FIGURE 8 : Revenue of changing Δ_2 in reference to Δ_1 at 0,1 € per coin and 1% transaction fee.

availability and inciting market pressure, user behavior can be quantitatively guided towards the desired target, demonstrating how the quantity of coins directly affects market dynamics.

Results

Application for Munich

The results for the city of Munich are shown in figure 9. The graphical representation of our analysis delineates the efficacy of distinct interventions to mitigate greenhouse gas (GHG) emissions in urban contexts. The green dotted line signifies the GHG emission targets established by central authorities for cities under study. Yellow bars present the anticipated GHG emissions based on person kilometer targets set by the city. According to our selected assumptions, the city is unlikely to maintain these targets, with emissions surpassing the designated limits by 2024.

Furthermore, the blue bars illustrate the projected GHG emissions upon implementing MobilityCoin price adjustments. Evidently, this strategy provides a robust theoretical framework to maintain emission targets. Meanwhile, the purple bars depict the emission outcomes resulting from the mode-shift scenario, whereby an approximate average of 8% passenger-kilometer per year is

Age	Number
0 – 17	241.232
18 – 44	654.301
45 – 64	398.903
≥ 65	267.692

TABLE 3 : Numbers of eligible users.

shifted from motorized individual transport (MIT) to public transport (PT). In this scenario, the city can successfully achieve the established emission reduction goals. In general, a threshold exists that indicates the compliance with set targets. E.g., users that underrun the value of $217,1gCO_2e$ on average during their travels work towards achieving the target in year 2022.

AS already mentioned, the agency has to carefully consider the values for the active modes incentives. Incentives bring new coins into the system which results in higher externalities. For instance, referring to the inhabitants data in ref table 3 and assuming users get 10.000 coins per month and gain 1 coin per person kilometer, a 10 km bike ride generates the amount of coins you need to spent travelling 1,05km with an internal combustion engine car. For one year, the entire amount of coins generated from incentives represent 0,89% of total number of coins circulating based on data of year 2018.

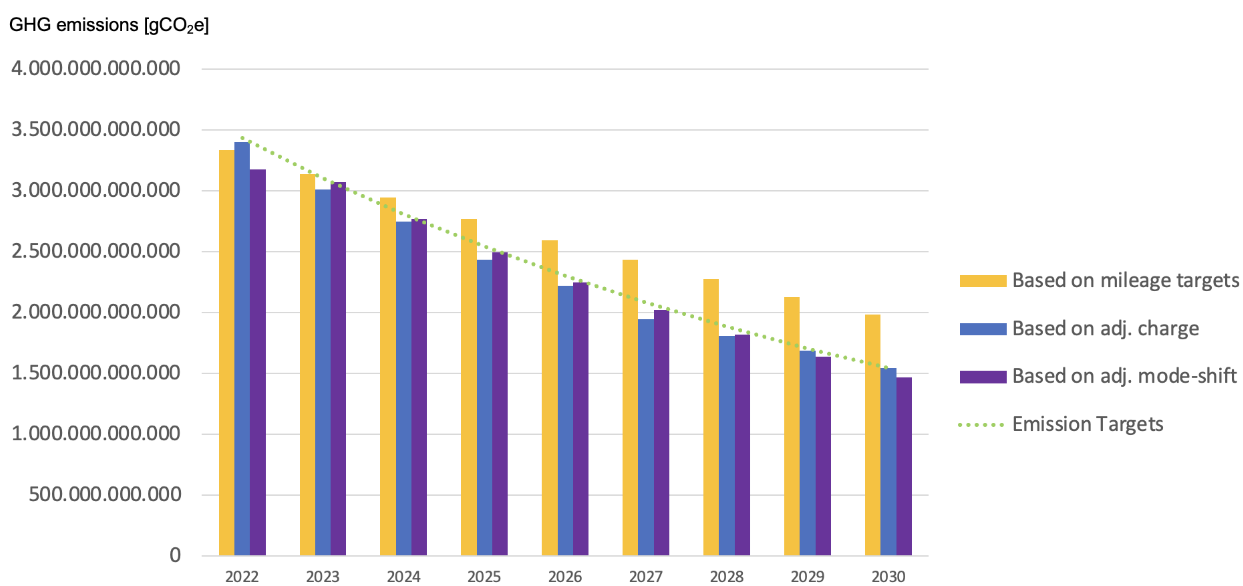

FIGURE 9 : Different scenarios for Munich.

Transaction Fee

We assume a transaction fee between $1\% - 5\%$ for each trade and a MobilityCoin market price of $0.1 - 0.5$€per coin whilst 0.0372 coins carry $1gCO_2e$. Therefore 1 MobilityCoin represents on average $0.11km$ MIT range, respectively $1.07km$ PT range.

Based on the aforementioned facts, the revenue potential of the MobilityCoin System is shown in fig. 10.

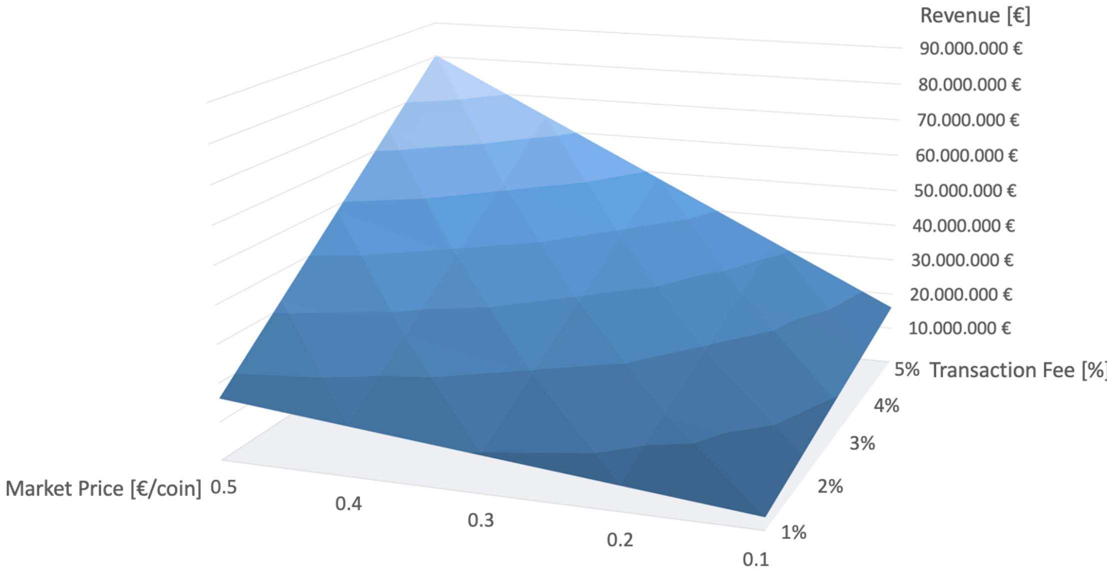

FIGURE 10 : Revenue potential for Munich ($\Delta_1 = \Delta_2$; Transaction Tax and Market Price).

In upcoming years, the German tax authorities will lack energy tax revenues due to the shift from internal combustion engines to electric vehicles. That decline is already clearly reflected in figures from EUR 40.7 billion in 2019 to EUR 33.7 billion in 2022 (*49*) of which 87.3% constitutes fuel (*50*), illustrated in fig. 11. The revenue gap for Munich amounts approximately between 86.539 million euros derived from mileage and 109.286 million euros derived from registered cars share. The predicted MobilityCoin tax revenues, shown in fig. 10, may be used to compensate said revenue shortfalls.

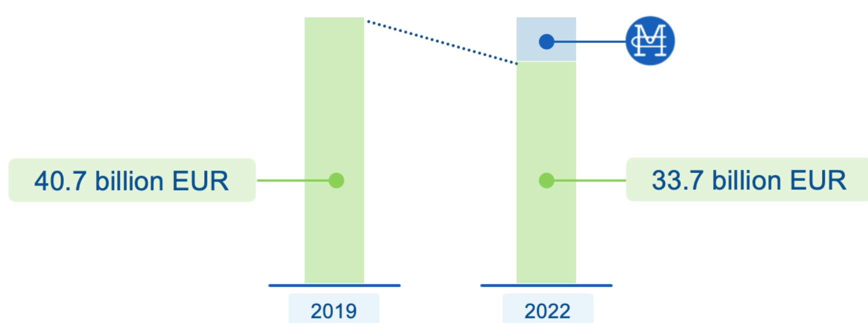

FIGURE 11 : Energy tax gap and MobilityCoin compensation.

DISCUSSION AND CONCLUSIONS

This paper provided a method to size the MobilityCoin System for a specific region. The presented model for the quantitative MobilityCoin analysis serves as a foundational illustration of the underlying mechanism. This conceptual framework can be further expanded and refined through future research to better understand and optimize its potential impact. The model and its components will be further developed to capture all system features, including crowdfunding and market. For the full presentation, we integrate more modes and heterogeneity in allocation and pricing which will include results for perception of MobilityCoin prices from a stated-preference survey with a sample size exceeding 1100 participants in the metropolitan area of Munich.

In general, the use of assumptions carry risks. Assumptions can lead to inaccurate predictions or conclusions. It is therefore important to be transparent about the underlying assumptions. The incorporated assumptions are balanced and critically evaluated to achieve accuracy and reliability.

In closing, the proposed method for sizing the MobilityCoin System brings the idea closer to a real-world application. The quantitative perspective can deliver potential advantages to transport policy. Furthermore, it can be used for the evaluation and calibration of a variety of TCS model applications. The obligation of the agency lies in making crucial decisions to keep the system in balance. The proposed method can comprehensively support this process. Therefore, the expansion and adaptation of this method for other metropolitan regions is desirable and necessary. The same applies to the revenue approximation. The results show potentials in revenue generation without taking trading behavior of different heterogeneous user groups into consideration - it demonstrates theoretic possibilities. The methodology can be extended in future research by heterogeneous characteristics of different user groups to make results more reliable.

AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: P. Servatius, A. Loder, K. Bogenberger; data collection: P. Servatius; analysis and interpretation of results: P. Servatius, A. Loder, K. Bogenberger; draft manuscript preparation: P. Servatius., A. Loder. All authors reviewed the results and approved the final version of the manuscript.

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