Qualification and Quantification of Fairness for Sustainable Mobility Policies

Camilla Quaresmini[1,*,†], Eugenia Villa[1,*,†], Valentina Breschi[2,†], Viola Schiaffonati[1,†] and Mara Tanelli[1,†]

[1]Politecnico di Milano, Via Ponzio 34/5, 20133 Milan, Italy
[2]Eindhoven University of Technology, 5612 AZ Eindhoven, Netherlands

Abstract
The adoption of new mobility technologies on a large-scale plays a crucial role to promote a green transition in the mobility field. Nonetheless, the acceptance of new mobility solutions implies radical changes in the everyday lives of individuals and, thus, it can be hampered by many different factors besides transport habits, such as socio-economic individual features. For this reason, it is essential to design human-centered policies directly addressing such barriers, avoiding the unwanted effect of amplifying inequalities at the edges of society. To this end, we propose a data-driven approach to embed socio-economic factors in the design of new mobility strategies that quantitatively account for fairness in a control-oriented and dynamic fashion. The formalization (and the inclusion in the approach) of the concepts of doxastic equality and equity allows us to mitigate epistemic exclusions, assessing system fairness. Thus, by combining tools from the control framework with those of philosophy, our approach offers an actionable tool for the support of the design of fair policies to foster the adoption of sustainable mobility habits.

Keywords
Sustainable mobility, Fairness, Epistemic injustice, Inclusive policy design, Optimal control

1. Introduction

The current climate emergency is prompting European governments to reach carbon neutrality in due course and, thus, to enact policies to attain this goal as soon as possible [6]. Most existing interventions aim to promote the adoption of alternative and sustainable mobility solutions, mainly due to the growing awareness of the mobility's impact on carbon emissions and energy consumption [12]. Nonetheless, initiatives enacted up to this moment have not resulted in the expected response from the population [15], with their success being largely variable across countries (despite their eventual similarities) and strongly dependent on the social contingency of the receiving communities. Among other reasons, this outcome is due to the limited consideration given by policymakers to social factors when designing such interventions, which undermines their final effectiveness. Indeed, while partially enhancing sustainable behaviors, the enacted policies have the unwanted effect of amplifying inequalities

EWAF'23: European Workshop on Algorithmic Fairness, June 07–09, 2023, Winterthur, Switzerland
*Corresponding author.
†These authors contributed equally.
camilla.quaresmini@polimi.it (C. Quaresmini); eugenia.villa@polimi.it (E. Villa); v.breschi@tue.nl (V. Breschi); viola.schiaffonati@polimi.it (V. Schiaffonati); mara.tanelli@polimi.it (M. Tanelli)
0000-0002-6474-1284 (C. Quaresmini); 0000-0002-5854-0486 (E. Villa); 0000-0002-1533-7349 (V. Breschi); 0000-0001-9127-6165 (V. Schiaffonati); 0000-0002-7172-0203 (M. Tanelli)

at the edges of society [4]. This issue thus demands new policy-making strategies that account for - and avoid - this side effect.

While quantitative approaches usually exploited for policy design ignore the epistemic charge of technical assumptions, purely qualitative methods pondering epistemological presuppositions risk being too general, bringing the issue to a high level of abstraction. To benefit from both these perspectives in designing diversity-aware, inclusive policies to foster the adoption of sustainable mobility habits our approach merges philosophical concepts and engineering tools, jointly making them active means to implement elements of fairness and reduce inequalities. By combining conceptual investigation and empirical study [9], this interdisciplinary coexistence allows us to philosophically characterize the quantitative aspects of policy design and integrate the philosophical concepts of epistemic injustice [8] and *credibility threshold* into policy-making, by translating them into their mathematical counterparts to achieve the goal. We benefit from these elements in devising a novel human-centered, dynamic, data-driven framework to design inclusive and sustainable mobility policies in feedback, rooted in optimal and predictive control theory (e.g., [3]). In the following, a more detailed description of both engineering tools and philosophical concepts exploited in our work is provided.

2. Human-Centered Mobility Policy Design

We exploit a data-driven approach to characterize individual propensity towards innovative transport modes and thus identify the main factors influencing their adoption. After a socio-economic characterization of each individual in a real or prototypical population is obtained, interactions between agents are modeled connecting them in a social network mathematically representing the influence of societal dictates on individual choices, e.g., changes in the personal opinions driven by homophily. Opinion dynamics models are then combined with the network to study how new mobility habits could spread based on a combination of personal attitudes and mutual influences. Finally, optimal control techniques are exploited to optimize diversity-aware incentive policies that effectively foster the adoption of new mobility solutions among the agents in the network.

2.1. The Mobility-DNA

In order to identify the main socio-economic barriers limiting the large-scale diffusion of innovative and sustainable mobility solutions, we leverage a European survey on mobility issues [7] to characterize the respondents (representing the prototypical population of each European country) from a socio-economic perspective. The survey contains 39 questions concerning personal information and mobility habits. Hence, considering as target the question assessing individual predisposition towards innovative and sustainable mobility solutions and exploiting machine-learning tools we are able to identify 7 primary factors influencing the target (*i.e.* environmental consciousness, income level, age, education, profession, mobility habits, country). Based on the answers to these attributes provided by each respondent, we are then able to build the so-called *Mobility-DNA* (denoted by $\mathcal{M}_i$ for respondent i), a compact yet comprehensive representation of the individual predisposition towards innovative and green mobility modes.

2.2. A Social Network to Model the Diffusion Process

As a first step towards a data-driven analysis of individual adoption patterns, we initially focus on prototypical populations. Specifically, by selecting a subset of nearly 1000 respondents of the survey living in the metropolitan area of a large city in Europe, we define our prototypical population where to study the diffusion of new mobility technologies. Relying on the homophily principle we build a social network by connecting agents based on the similarity of their *MobilityDNA*s, assuming that individuals with similar profiles are more likely to interact and thus influence each others. By modeling the network as an undirect graph $G = (V, E)$, we can exploit a mathematical characterization of opinion dynamics such [1] to describe how new mobility habits could spread across the network based on a combination of personal attitudes and mutual influences. Specifically, relying on an Irreversible Cascade Model [10], we assume that each agent i at time t can be either an adopter (state $x_i(t) = 1$) or non-adopter (state $x_i(t) = 0$), remaining an adopter once turned into one. We further assume that the adoption dynamics can be described as follows:

$$x_i(t+1) = \begin{cases} 1, & x_i(t) = 1 \text{ or } \frac{1}{|N_i|} \sum_{s \in N_i} x_s(t) \geq \rho_i(t) \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

where $N_i = s \in V : (s, i) \in E$ the set of neighbors of the node $i \in V$ and $\rho_i = 1 - \text{Avg}(\mathcal{M}_i)$ the is the individual resistance to new mobility solutions, with $\text{Avg}(\mathcal{M}_i)$ being the average of the DNA components. Considering the resistance constant over time, this model allows us to study the diffusion of new mobility solutions triggered only by social influence, namely when no external incentives are allocated.

2.3. Optimal Policy Design

To finally model the effects of incentives allocated by policy-makers to boost the diffusion process, we allow the index of individual resistance to vary over time, and specifically to be reduced thanks to the effect of external inputs $u_i(t)_{i \in V}$ following the dynamic:

$$\rho_i(t+1) = \rho_i(t) - \beta_i u_i(t) \quad \forall t \in [0, T], i \in V \quad (2)$$

where β_i is a parameter representing the individual propensity to accept external incentives. To optimally define the sequence of inputs $\{u_i(t)\}_{i \in V}$, we exploit optimal control techniques to design fostering strategies that maximize the number of adopters (and thus the boosting power of the policy), while promoting cost savings. In particular, the cost function is defined as the weighted combination of two components: one finalized at minimizing individual resistances and thus representing the fostering power of the policy, the other finalized at minimizing the allocated incentives.

3. Mitigating Epistemic Injustice

Despite the huge number of approaches in the literature, fairness is often intended as the just treatment without discrimination. We introduce the concept in our modeling framework by declining it into two criteria [2]: *equality*, i.e., attaining an even distribution of the available resources regardless of the differences in socio-economic statuses, and *equity*, namely promoting agents to be comparably close to the final target of adoption by re-balancing individuals' initial attitudes through diversified external incentives. Nonetheless, knowing that fairness is all but static [5], the proposed framework allows for dynamical changes in how elements of fairness are integrated into the decision-making process, along with variations in the individuals' interactions and personal characteristics.

Nevertheless, considering equality and equity principles is not sufficient for assessing fairness. Furthermore, while emphasis is usually laid to the ethical dimension (e.g. [11, 13]), we want to extend the notion of fairness in an epistemic direction, which is crucial in a context where agents share information. A way to consider the epistemic dimension is to reason about credibility. Thus, we claim that the identity power of the agents [8], i.e., the epistemic charge of agents' social features, has a significant impact on their credibility, so that the epistemic dimension of the problem cannot be neglected when modeling social interactions. Indeed, first, agents have to decide whether to trust other agents' ability to adopt a new mobility technology. Second, if individuals are credible they can also act as opinion resources, being useful to spread the adoption. Third, credibility is crucial in maximizing agents' power of influence. Furthermore, in a network where agents are connected through the homophily principle, i.e. agents interact only with similar ones, the identity power leads to epistemic exclusions. In this way non-similar, unconnected agents suffer a credibility deficit [8] due to their social features. Thus, we propose to raise the credibility of discriminated agents up to a credibility threshold, defined as:

Definition 1 (Credibility Threshold)**.** *An agent i is considered credible over a time frame $\mathcal{T} := \{t_1, \ldots, t_n\}$ denoted as $Credible_{\mathcal{T}}(i)$ iff $c_{\mathcal{T}}(i) \geq \pi$, for some safe value π.*

In other words, by allocating credibility resources, an agent becomes credible if the value of c exceeds or is equal to the safe value π. This allows us to resolve the discrimination involved by the homophily principle, as mitigating the lack of credibility, epistemic exclusions are no longer present in the network. These considerations allow us to define two new criteria to embed the epistemic dimension into the problem. We offer a first formalization below. *Doxastic equality* ensures that every group is given an equal amount of credibility to reach the credibility threshold. We formalize this principle by adapting the statistical parity formula [14] as follows.

Definition 2 (Doxastic Equality)**.** *A system is doxastically equal among agents which have ($A = 1$) or not ($A = 0$) some sensitive social feature if it satisfies*

$$p(c(i) = \pi \mid A = 0) = p(c(i) = \pi \mid A = 1)$$

where $c(i) = \pi$ indicates the reaching of the credibility threshold by an agent i.

Doxastic equity allocates the groups appropriate credibility to reach the threshold, increasing the initial credibility to compensate for the credibility deficit as

Definition 3 (Doxastic Equity)**.** *A system is doxastically equitable among agents which have ($A = 1$) or not ($A = 0$) some sensitive social feature if it satisfies*

$$p(c(i)_{t_{n-m}} \mid A = 0) + p(c(i)_{t_n} \mid A = 0) = p(c(i)_{t_{n-m}} \mid A = 1) + p(c(i)_{t_n} \mid A = 1)$$

where $c(i)_{t_{n-m}}$ is the initial credibility of an agent i, and $c(i)_{t_n}$ the updated one.

4. Final Remarks

This work aims at proposing a quantitative tool built on a philosophically justified model, meaning that formal concepts are the result of philosophical analysis, for the design of fair policies to maximize the adoption of sustainable mobility habits, while minimizing waste of resources. To this end, a data-driven approach is introduced to embed socio-economic factors in the design of mobility strategies, quantitatively accounting for fairness in a control-oriented and dynamic fashion. The proposed strategy to address fairness in this specific context is that of doing two parallel works, i.e. one on the economic resources and one on the epistemic ones. The epistemic dimension is thus introduced in our model through the concept of credibility, which allows to conceptualize and formalize the two new principles of doxastic equality and equity. In this way we want to verify if increasing agents' credibility could have a positive impact on the distribution of economic resources. Furthermore, given that the propagation of opinion is more efficient when it involves agents with more credibility, we expect our theoretical analysis to show that adoption can be speed up if classes of agents are not discriminated. The proposed strategy could also lead to the mitigation of epistemic exclusions derived by the homophily principle, allowing to incorporate fairness in the policy design process.

References

[1] D. Acemoglu, A. Ozdaglar, and E. Yildiz. Diffusion of innovations in social networks, 2011.

[2] R. J. Arneson. Equality and equal opportunity for welfare. *Philosophical Studies: An International Journal for Philosophy in the Analytic Tradition*, 56(1):77–93, 1989.

[3] A. Bemporad and M. Morari. Control of systems integrating logic, dynamics, and constraints. *Automatica*, 35(3):407–427, 1999.

[4] Reuben Binns. Fairness in machine learning: Lessons from political philosophy. *CoRR*, abs/1712.03586, 2017.

[5] A. D'Amour, H. Srinivasan, J. Atwood, P. Baljekar, D. Sculley, and Y. Halpern. Fairness is not static: deeper understanding of long term fairness via simulation studies, 2020.

[6] European Commssion. *European Green Deal*. 2021.

[7] D. Fiorello, L. Zani, P. Christidis, and E. Navajas Cawood. EU survey on issues related to transport and mobility, 2015. LF-NA-27334-EN-N.

[8] M. Fricker. *Epistemic Injustice: Power and the Ethics of Knowing*. Oxford University Press, 2007.

[9] B. Friedman and D. Hendry. *Value Sensitive Design: Shaping Technology with Moral Imagination*. 2019.

[10] M. Granovetter. Threshold models of collective behavior. *The American Journal of Sociology*, 83(6):1420–1443, 1978.

[11] Hoda Heidari, Michele Loi, Krishna P. Gummadi, and Andreas Krause. A moral framework for understanding of fair ML through economic models of equality of opportunity. *CoRR*, abs/1809.03400, 2018.

[12] Y. Kazancoglu, M. Ozbiltekin-Pala, and Y. D. Ozkan-Ozen. Prediction and evaluation of greenhouse gas emissions for sustainable road transport within europe, 2021.

[13] Michelle Seng Ah Lee, Luciano Floridi, and Jatinder Singh. Formalising trade-offs beyond algorithmic fairness: Lessons from ethical philosophy and welfare economics. *AI and Ethics*, 3, 2021.

[14] Ninareh Mehrabi, Yuzhong Huang, and Fred Morstatter. Statistical equity: A fairness classification objective. *CoRR*, abs/2005.07293, 2020.

[15] N. Wang, L. Tang, and H. Pan. A global comparison and assessment of incentive policy on electric vehicle promotion, 2019.